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LOADS AND AEROELASTICITY DIVISION RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR FY 1982 AND PLANS FOR FY 1983

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LOADS AND AEROELASTICITY DIVISION
RESEARCH AND TECHNOLOGY ACCOMPLISHMENTS FOR FY 1982
AND PLANS FOR FY 1983

SUMMARY

The purpose of this paper is to present the Loads and Aeroelasticity Division's research accomplishments for FY 82 and research plans for FY 83. The work under each branch (technical area) will be described in terms of highlights of accomplishments during the past year and highlights of plans for the current year as they relate to five year plans and the objectives for each technical area. This information will be useful in program coordination with other government organizations and industry in areas of mutual interest.

ORGANIZATION

The Langley Research Center is organized by directorates as shown on figure 1. The top three perform support functions and the bottom four conduct the research program. A directorate is organized into divisions as illustrated on the figure for the Structures Directorate.

The Loads and Aeroelasticity Division (LAD) consists of four branches as shown on figure 2. This figure lists the key people in the division which consists of 70 NASA civil servants and five members of the Army Structures Laboratory (of the Army Aviation Research and Development Command) located at the Langley Research Center. Each branch represents a technical area and disciplines under the technical areas are also shown. All of the Army personnel work on the discipline Rotorcraft Aeroelasticity.

The division conducts analytical and experimental research in the four technical areas to meet technology requirements for advanced aerospace vehicles. The research focuses on the long range thrusts shown in figure 3 with the LAD having lead responsibility in the first three. The Unsteady Aerodynamics Branch (UAB), Configuration Aeroelasticity Branch (CAB), and Multidisciplinary Analysis and Optimization Branch (MAOB) all work in the area of Control of Aeroelastic Stability and Response. The MAOB also works the area of Computerized Analysis and Synthesis. The Aerothermal Loads Branch (ALB) works the area of TPS for Advanced STS and performs most of the research in the last three thrusts which the LAD supports.

FACILITIES

The Loads and Aeroelasticity Division has two major facilities available to support its research as shown in figure 4.

The Transonic Dynamics Tunnel (TDT) is a M 0.2 to 1.2 continuous flow variable pressure wind tunnel with a 16 ft. square test section which uses a freon-12 test medium primarily for dynamic aeroelastic testing. The tunnel operates at dynamic pressures up to 25 psi and Reynolds numbers up to 8×10^6/ft. This unique facility is used primarily by the Configuration Aeroelasticity Branch using side-wall mounted models and cable-mounted models (figure 4) of conventional type aircraft. On occasions, the ARES (Aeroelastic Rotor Experimental System) test stand is used in the tunnel to study the aeroelastic effects on rotors. A Hover Facility, located in B-647, is used to set-up the ARES test stand in preparation for entry into the TDT. A modernization of the TDT Data Acquisition System is underway along with a major CofF activity for density increase. Replacement cost for this facility is $57M.

The Aerothermal Loads Complex consists of six facilities which are used solely by the Aerothermal Loads Branch to carry out their research. The 8-Foot High Temperature Tunnel (8' HTT) is a unique hypersonic Mach 7 blowdown wind tunnel with an 8' diameter test section (usable test core of 4') that uses products of combustion (methane and air under pressure) as the test medium. The tunnel operates at dynamic pressures of 2 to 12 psi, temperatures of 2000 to 3000°F and Reynolds numbers of 0.3 to 3.0 x 10^6/ft. The tunnel is used to test flat and curved surface type models to determine aerothermal effects and to evaluate new concepts for Thermal Protection Systems (TPS). A major CofF item is being proposed to provide alternate Mach number cabability and to provide O_2 enrichment for the test medium. This is being done primarily to allow the tunnel to test models that have hypersonic air breathing propulsion applications. Replacement cost for the tunnel is $41M.

The 7-Inch High Temperature Tunnel (7" HTT) is a 1/12 scale of the 8' HTT with basically the same capabilities as the larger tunnel. It is used primarily for blockage studies for models being placed in the 8' and also it is used to aid in the design of larger models. The cost of models is greatly reduced by trying out scaled models in the small tunnel. The 8' could damage very expensive models if certain system checks and tunnel operating conditions had not been defined first using this facility. The 7" HTT is currently being worked to upgrade its control system and to also provide O_2 enrichment so its capability can stay current with the 8' HTT. This will also aid in the development of the 8' HTT O_2 enrichment system. Replacement cost for the tunnel is $0.8M.

The 1 x 3 High Enthalpy Aerothermal Tunnel (1 x 3 HEAT) is a unique facility designed to provide realistic environments and times for testing thermal protection systems proposed for use on high-speed vehicles such as the Space Shuttle. The facility is a hypersonic blowdown wind tunnel that uses products of combustion as the test medium. Test panels mounted on the sidewalls can be as large as 2' high x 3' long. The facility operates at dynamic pressures of 1 to 10 psi, Mach numbers from 4.7 to 3.5 depending on the temperatures, temperatures from ambient to 5800°F, an altitude range simulating flight of 130,000 to 80,000 ft., and Enthalpy levels from 1100 to 4400 BTU/lb depending on the oxygen levels used in the test medium. Replacement cost for the tunnel is $8M.

The three Aerothermal Arc Tunnels (20 MW, 5 MW and 1 MW) are used to test models in an environment that simulates the flight reentry envelope for high speed vehicles such as the Space Shuttle. The amount of usable energy to the test medium in these facilities is 9 MW, 2 MW, and 1/2 MW. The 5 MW is a three phase AC arc heater while the 20 MW and 1 MW are DC arc heaters. Test conditions such as temperature, flow rate, and enthalpy vary greatly since a variety of nozzles and throats are available and since model sizes are different (3" diameter to 1' x 2' panels). The AAT has a CofF activity proposed to increase the steam supply line capacity. Replacement cost for these arc tunnels are $22M.

FY 82 ACCOMPLISHMENTS

Aerothermal Loads Branch

The Aerothermal Loads Branch conducts research (figure 5) to develop and validate solution algorithms, modeling techniques, and integrated elements for thermal-structural analysis and design; to identify and understand flow phenomena and flow/surface interaction parameters required to define detailed aerothermal loads for structural design via analysis and test; and to verify practical and durable thermal protection system concepts for space transportation systems via analysis, laboratory, and wind tunnel tests. This work is more clearly identified in figure 6 which shows the five year plan of the four disciplines and their expected results. The numbers refer to the accomplishments listed in figure 7.

The Aerothermal Loads FY 82 accomplishments listed below are highlighted by figures 8 through 18.

TPS Concepts:
- Second Generation Titanium Multiwall TPS Tile Successfully Fabricated
- Superalloy Honeycomb Prepackaged TPS Tile Successfully Fabricated
- LaRC tests in 20 MW AAT Certify FRCI-12 for Single Mission
- Graphite/Polyimide Panel with Direct Bond RSI Tiles Survives Simulated Shuttle Ascent Acoustics

Thermal Loads:
- Flow Angularity effects on Tile/Gap Impingement Heating
- Heat Transfer Model Using New Fabrication Technique Tested in 8' HTT
- Unsealed Wing-Elevon Cove Heating Characteristic at M = 6.8 for Separated Flow on Wing

Integrated Analysis:
- New View Factor Calculation Technique More Efficient
- Analysis of Pressure and Heating Rate Distributions on a Thermally Bowed TPS Panel

Facilities Operations and Development:
- 8' HTT Ceramic Nozzle Evaluation
- Second Minimum Nozzle Insert Yields Uniform Mach Number Reduction

Each highlight is accompanied by descriptive material.

Multidisciplinary Analysis and Optimization Branch

The Multidisciplinary Analysis and Optimization Branch conducts research (figure 19) to develop a methodology for optimization of aircraft and spacecraft for best performance, and to develop the technology to reduce loads and increase the dynamic structural stability of flexible airframes by the use of active controls; to obtain transonic loads data and validate methods for aeroelastic design, including active control concepts, through wind tunnel and flight tests utilizing drone aircraft; and to develop and validate thermal-structural analysis and design methods tailored for repetitive application in optimization under a variety of constraints and loads. This work is more clearly identified in figure 20 which shows the five year plan of the four disciplines and their expected results. The numbers refer to the FY 82 accomplishments listed in figure 21.

The Multidisciplinary Analysis and Optimization FY 82 accomplishments listed below are highlighted by figures 22 through 25.

Active Controls:
- DAST ARW-1R FSS Performance

Design Oriented Analysis:
- Implementation of Static and Dynamic Structural Sensitivity Calculations

Flight Loads:
- DAST ARW-1R Ground Vibration Test

Optimization and Applications:
- Multilevel Optimization

Each highlight is accompanied by descriptive material.

Unsteady Aerodynamics Branch

The Unsteady Aerodynamics Branch conducts research (figure 26) to produce, apply, and validate through experiments a set of analytical methods for predicting steady and unsteady aerodynamic loads and aeroelastic characteristics of flight vehicles--with emphasis on the transonic range. This work is more clearly identified in figure 27 which shows the five year plan of the three disciplines and their expected results. The numbers refer to the FY 82 accomplishments listed in figure 28.

The Unsteady Aerodynamic FY 82 accomplishments listed below are highlighted by figures 29 through 33.

Theory Development:
- Improved Method for Two-Dimensional Unsteady Transonic Flow Analysis (XTRAN2L)

Aeroelastic Analysis:
- Experimental Angle-of-Attack Sensitive Flutter Studied with Modified Strip Analysis
- Experimental and Calculated Effects of Angle-of-Attack upon Transonic Flutter

Unsteady Pressure Measurements:
- Transonic Pressure Distributions Measured on a Rectangular Supercritical Wing Oscillating in Pitch
- Unsteady Pressures Measured on a Clipped Delta Wing Provide Data for Transonic Code Validation

Each highlight is accompanied by descriptive material.

Configuration Aeroelasticity Branch

The Configuration Aeroelasticity Branch conducts research (figure 34) to produce, apply, and validate through experiments a set of analytical methods for predicting steady and unsteady aerodynamic loads and aeroelastic characteristics of rotorcraft; to determine, analytically and experimentally, effective means for predicting and reducing helicopter vibrations and to evaluate the aeroelastic characteristics of new rotor systems; to develop the aeroelastic understanding and prediction capabilities needed to apply new aerodynamic and structural concepts to future flight vehicles and to determine and solve the aeroelastic problems of current designs; and to design, fabricate, and flight test a pylon which will suppress wing/store flutter. This work is more clearly identified in figure 35 which shows the five year plan of the three disciplines and their expected results. The numbers refer to the FY 82 accomplishments listed in figure 36.

The Configuration Aeroelasticity FY 82 accomplishments listed below are highlighted by figures 37 through 49.

Aircraft Aeroelasticity:
- Vertical Tail of New Supersonic Cruise Fighter Airplane (F-16) shown Free from Transonic Flutter
- New F-16E Fighter Configurations Flutter Cleared in TDT for Flight Demonstration Tests
- F-16 Flutter Suppression Systems Evaluated in TDT Tests
- Digital Active Flutter Suppression Systems Demonstrated in TDT Tests
- An Adaptive Digital Active Flutter Suppression System Demonstrated in TDT Tests
- Flutter of Aeroelastically Tailored Quick-Roll Wing Predictable by Conventional Analysis
- Supercritical Airfoil Lowers Transonic Flutter Boundary of Large Transport Wing with Engines
- Evaluation of Four Subcritical Response Methods for On-Line Prediction of Flutter Onset in Wind Tunnel Tests

Rotorcraft Aeroelasticity:
- Parametric Tip Effects Determined for Conformable Rotor Applications
- Flight Test of Manually Operated Higher Harmonic Control System Complete
- Comprehensive Design Procedure Developed for Pendulum Vibration Absorbers for Rotor Blades

Rotorcraft Vibrations:
- A Formulation of Rotor-Airframe Coupling for Design Analysis of Vibrations of Helicopter Airframes
- Planning, Creating, and Documenting a Finite Element Vibrations Model of a Helicopter

Each highlight is accompanied by descriptive material.

PUBLICATIONS

The FY 82 accomplishments of the Loads and Aeroelasticity Division resulted in a number of publications. The publications are listed below and are identified by the catagories of journal publications, formal NASA reports, conference presentations, contractor reports, and other.

Journal Publications

1. Green, W. H.; and Sobieski-Sobieszczanski, J.: Minimum Mass Sizing of a Large Low-Aspect Ratio Airframe for Flutter-Free Performance. J. Aircraft, Vol. 19, No. 3, March 1982.

2. Bennett, R.; and Abel, I.: Flight Flutter Test and Data Analysis Techniques Applied to a Drone Aircraft. J. of Aircraft, Vol. 19, No. 7, July 1982.

3. Shideler, J.; Kelly, N.; Avery, D.; Blosser, M.; and Adelman, H.: Multiwall TPS - An Emerging Concept. J. Spacecraft, Vol. 19, No. 4, July 1982.

4. Mukhopadhyay, V.; Newsom, J. R.; and Abel, I.: Reduced-Order Optimal Feedback Control Law Synthesis for Flutter Suppression. J. of Guidance, Control, and Dynamics, July 1982.

5. Sobieski-Sobieszczanski, J.; Barthelemy, J. F.; and Riley, K. M.: Sensitivity of Optimum Solutions of Problem Parameters. AIAA Journal, Vol. 20, No. 9, Sept. 1982.

Formal NASA Reports

6. Kvaternik, Raymond; and Walton, W.: A Unified Formulation of Rotor-Airframe Coupling for Design Analysis of Vibrations of Helicopter Airframes. NASA RP-1089, June 1982.

7. Weinstein, I.; Avery, Don E.; and Hunt, L. Roane: Aerodynamic Heating on the Corrugated Surface of a 10.2° Half-Angle Blunted Cone at Mach 6.7. NASA TP-1928, December 1981.

8. Yeager, W. T. Jr.; and Mantay, Wayne R.: Wind-Tunnel Investigation of the Effects of Blade Tip Geometry on the Interaction of Torsional Loads and Performance for an Articulated Helicopter Rotor. NASA TP-1926, December 1981.

9. Avery, Don E.; Shideler, John L.; and Stuckey, Robert N.: Thermal and Aerothermal Performance of a Titanium Multiwall Thermal Protection System. NASA TP-1961, December 1981.

10. Murrow, H. N.; McCain, W. E.; and Rhyne, R. H.: Power Spectral Measurements of Clear-Air Turbulence to Long Wavelengths for Altitudes Up to 14,000 Meters. NASA TP-1979, April 1982.

11. Abel, Irving; Perry, Boyd, III; and Newsom, Jerry R.: Comparison of Analytical and Wind-Tunnel Results for Flutter and Gust Response of a Transport Wing with Active Controls. NASA TP-2010, June 1982.

12. Adelman, H. M.; Haftka, R. T.; and Robinson, J. C.: Studies of Implicit and Explicit Solution Techniques in Transient Thermal Analysis of Structures. NASA TP-2038, August 1982.

13. Sandford, M. C.; Ricketts, R. H.; and Watson, Judith J.: Subsonic and Transonic Pressure Measurements on a High-Aspect-Ratio Supercritical-Wing Model with Oscillating Control Surfaces. NASA TM-83201, November 1981.

14. Rogers, J. L., Jr.; Sobieski, J.; and Bhat, R.: An Implementation of the Programing Structural Synthesis System (PROSSS). NASA TM-83180, December 1981.

15. Rogers, J. L., Jr.: An Implementation of the Distributed Programing Structural Synthesis System (PROSSS). NASA TM-83253, December 1981.

16. Giles, Gary; and Vallas, Maria: An Automated Data Management/Analysis System for Space Shuttle Orbiter Tiles. NASA TM-83261, January 1982.

17. Sobieski, J.: A Linear Decomposition Method for Large Optimization Problems - Blueprint for Development. NASA TM-83248, February 1982.

18. Heldenfels, R. R.: Historical Perspectives on Thermostructural Research at the NACA Langley Aeronautical Laboratory from 1948 to 1958. NASA TM-83266, February 1982.

19. Albertson, Cindy W.: Blockage and Flow Studies of a Generalized Test Apparatus Including Various Wing Configurations in the Langley 7-Inch Mach 7 Pilot Tunnel. NASA TM-83301, March 1982.

20. Bland, Samuel R.: Development of Low-Frequency Kernel-Function Aerodynamics for Comparison with Time-Dependent Finite-Difference Methods. NASA TM-83283, May 1982.

21. Watson, Judith J.: Elastic Deformation Effects on Aerodynamic Characteristics for a High-Aspect-Ratio Supercritical-Wing Model. NASA TM-83286, May 1982.

22. Cunningham, H. J.; Desmarais, R. N.; and Yates, E. Carson: Steady, Oscillatory, and Unsteady Subsonic and Supersonic Aerodynamics - Production Version 1.1 (SOUSSA - P1.1). NASA TM-84484, May 1982.

23. Perry, Boyd, III: Methodology for Determining Elevon Deflections to Trim and Maneuver the DAST Vehicle with Negative Static Margin. NASA TM-84499, May 1982.

24. Johnson, Sally C.: Programs for Transferring Data Between A Relational Data Base and a Finite-Element Structural Analysis Program. NASA TM-84512, June 1982.

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29. Sobieski, J.; and Rogers, J. L.: A Programing System for Applications and Research in Structural Optimization. Presented at the International Symposium on Optimum Structural Design - 11th Naval Structural Mechanics Symposium, Tucson, AZ, October 19-22, 1981. NASA TM-83191.

30. Giles, G.; and Vallas, M.: Use of an Engineering Data Management System In the Analysis of Space Shuttle Orbiter Tiles. Presented at the AIAA Computers in Aerospace III Conference, San Diego, CA, October 26-28, 1981. AIAA-81-2192, NASA TM-83215.

31. Computational Aspects of Heat Transfer in Structures. Proceedings of a Symposium held at NASA Langley Research Center, Hampton, VA, November 3-5, 1981. NASA CP-2216.

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34. Camarda, Charles J.: Evaluation of an Improved Finite-Element Thermal Stress Calculation Technique. Presented at the Computational Aspects of Heat Transfer in Structures Conference, Hampton, VA, November 3-5, 1981. NASA CP-2216.

35. Shore, Charles P.: Status Report on Development of a Reduced Basis Technique for Transient Thermal Analysis. Presented at the Computational Aspects of Heat Transfer in Structures Conference, Hampton, VA, November 3-5, 1981. NASA CP-2216.

36. Blosser, M. L.: Transient Thermal Analysis of a Titanium Multiwall Thermal Protection System. Presented at the Computational Aspects of Heat Transfer in Structures Conference, Hampton, VA, November 3-5, 1981. NASA CP-2216.

37. Heldenfels, Richard R.: Historical Perspectives on Thermostructural Research at the NACA Langley Aeronautical Laboratory from 1948 to 1958. Presented at the Computational Aspects of Heat Transfer in Structures Conference, Hampton, VA, November 3-5, 1981. NASA CP-2216.

38. Robinson, J. C.; Riley, K. M.; and Haftka, R. T.: Evaluation of the SPAR Thermal Analyzer on the Cyber-203 Computer. Presented at the Computational Aspects of Heat Transfer in Structures Conference, Hampton, VA, November 3-5. 1981. NASA CP-2216.

39. Adelman, H.; Haftka, R.; and Robinson, J.: Some Aspects of Algorithm Performance and Modeling in Transient Thermal Analysis Structures. Presented at the ASME Winter Annual Meeting, Washington, DC, November 15-20, 1981. NASA TM-83190.

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41. Mehrotra, Sudhir C.; and Robinson, James C.: Structural Modeling of High Reynolds Number Wind Tunnel Models. Presented at the AIAA 12th Aerodynamic Testing Conference, Williamsburg, VA, March 22-24, 1982. AIAA-82-0602.

42. Farmer, Moses G.: A Two-Degree-of-Freedom Flutter Mount System with Low Damping for Testing Rigid Wings at Different Angles of Attack. Presented at the Virginia Academy of Science Meeting, Blacksburg, VA, April 20-23, 1982. NASA TM-83302.

43. Desmarais, R. N.: An Accurate Method for Evaluating the Kernel of the Integral Equation Relating Lift to Downwash in Unsteady Potential Flow. Presented at the AIAA/ASME/ASCE/AHS, 23rd Structures, Structural Dynamics and Materials Conference, New Orleans, LA, May 10-12, 1982. AIAA-82-687, NASA TM-83281.

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56. Kelly, H. N.; and Webb, G. L.: Assessment of Alternate Thermal Protection Systems for the Space Shuttle Orbiter. Presented at the AIAA/ASME 3rd Joint Thermophysics, Fluids, Plasma and Heat Transfer Conference, St. Louis, MO, June 7-11, 1982. AIAA-82-0899, NASA TM-84491.

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63. Hays D.: An Assessment of Alternate Thermal Protection Systems for the Space Shuttle Orbiter, Vol I - Executive Summary. NASA CR-3548, April 1982.

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78. Bland, Sam: AGARD Three-Dimensional Aeroelastic Configurations. Prepared for AGARD, March 1982. AGARD-AR-167.

79. Young, W. W.: Design and Prediction for Rotor Blade Aerodynamics. Presented at the AGARD Fluid Dynamics Panel, London, England, May 17-18, 1982. AGARD-CP-334.

80. Grosser, W. F.; Britt, R. T.; Childs, C. B.; Crooks, O. J.; and Cazier, F. W.: A High-Speed Wind-Tunnel Study of the Flutter and Steady/Unsteady Aerodynamic Characteristics of a Supercritical Versus Conventional Airfoil Transport Wing. Presented at the 55th AGARD Structures and Materials Panel, Toronto, Canada, September 20-24, 1982.

FY 83 PLANS

The FY 83 plans for the Loads and Aeroelasticity Division are broken out by each of the branches (technical areas) and are referred to in terms of the five year plans by the letters A, B, C, . . . on figures 6, 20, 27, and 35, respectively.

Aerothermal Loads Branch

For FY 83, there will be an increasing level of activity in all four disciplines.

TPS Concepts. - The in Aerothermal Loads Branch effort in development of durable TPS in 1983 will be directed toward testing of 1) the titanium and superalloy panels described in the 1982 review and 2) an Advanced Carbon Carbon (ACC) multipost concept for application where vehicle surfaces exceed the use temperature of the metallic panels. The metallic panels will be exposed to static heating, wind tunnel, vibration, acoustic, water intrusion, foreign object damage, and lightning strike tests. Current plans call for static heating, arc tunnel, and foreign object damage tests of the ACC concept. The proposed testing will provide a verification of durable TPS concepts for a temperature range from 700°F to over 2300°F that are mechanically attached, have no open gaps, and are mass competitive with ceramic TPS currently employed on the Space Shuttle.

Thermal Loads. - The major thrusts of the thermal loads research effort for FY 83 consists of five specific tasks: 1) results of mass addition film cooling tests of a large 12.5 degree cone will be analyzed to determine the cooling effectiveness of both forward facing and tangential coolant ejection. 2) A Curved Surface Test Apparatus (CSTA) will be tested to define the aerothermal loads on a fuselage type body for comparison with the latest flow field analytical methods and to provide baseline data for using the CSTA as a test bed. 3) Experimental results of flat TPS tile gap heating as a function of flow angularity will be analyzed and a tile gap model will be designed to fit the CSTA to study the effects of large pressure gradients along curved surfaces on gap heating. 4) A wind tunnel model with shallow spherical protuberances that simulate thermally bowed metallic TPS tiles and a model that simulates a chordwise gap formed between adjacent wing elevons will be prepared for testing. 5) Generic models will be designed for investigating effects of protuberances submerged within and extended through a turbulent boundary layer and for investigating flow interference effects of inside corners.

Integrated Analysis. - There are two major thrusts for the Aerothermal Loads Branch analysis effort. The first, which complements the thermal loads experimental effort, is the prediction of aerothermal loads. This effort includes continued application of finite difference solutions to complex flow configurations and development of finite element technology for aerothermal load prediction with the long-range goal of developing an integrated flow-thermal-structural analysis capability. The second, which addresses integrated thermal-structural analysis, includes improvement of techniques, algorithms, and radiation analysis for applications to Space Shuttle and Large Space Structures Technologies.

Facilities Operations and Development. - The facilities effort involves the safe and efficient operation and the expansion of the test capabilities of the six high energy facilities of the Aerothermal Loads Branch--the 8' High Temperature Tunnel (8' HTT), 1' x 3' High Enthalpy Aerothermal Tunnel (1' x 3' HEAT), the 7" High Temperature Tunnel (7" HTT), and the 1, 5, and 20 MW Aerothermal Arc Tunnels.

A major thrust will be the verification testing in the 7" HTT of techniques for providing alternate Mach numbers (4, 4.5, and 5) and oxygen enrichment of the methane air combustion products test stream. This effort is in support of a proposed modification (FY 85 CofF) of the 8' HTT which will make it a unique national research facility for testing air-breathing propulsion systems for very high speed aircraft and missiles.

During the next year the Curved Surface Test Apparatus (CSTA), Superalloy and Titanium TPS, Sentry Missile Thrustor, and a flow breakdown load definition model will be tested in the 8' HTT. A flow survey apparatus which can survey the test conditions before every run will be installed, the computerized data system which allows graphical output of data in real time and quick look post run data will be completed, a replacement approach section will be installed, the Lifting Surface Test Apparatus (LSTA) will be functionally checked out, and new radiant heater banks for the LSTA and the associated power controllers will be installed.

The 1' x 3' High Enthalpy Aerothermal Tunnel will be reactivated, a new water cooled combustor liner will be installed, and calibration of the facility will be initiated.

The test programs for the next year for the arc heated tunnels include: 1) basic metallic heat shield material evaluation; 2) a basic research program on the catalysis of recombination of gaseous atoms on metal oxide surfaces; 3) testing support for the evaluation of the ablator for the external tank of the Shuttle; 4) advanced TPS certification and trouble spot testing for Shuttle as required; 5) a rocket motor materials evaluation; 6) Advanced Carbon-Carbon (ACC) TPS panel tests; 7) evaluation of a new arc heater concept; and 8) basic electrode erosion studies.

The plans/milestones marked on figure 6 are described in more detail in figure 50. Selected highlights of these milestones are listed below and are shown by figures 51 through 57.

TPS Concepts:
- Metallic Thermal Protection Systems
- Advanced Carbon-Carbon Heat Shield Research

Thermal Loads:
- Mass Addition Film Cooling Tests of a 12.5 Degree Cone in the 8' HTT
- Aerodynamic Heating and Pressure Distributions on a Blunted Three-Dimensional Nonaxisymmetric Body at Mach 6.8
- General Purpose Test Apparatus for 8' HTT

Integrated Analysis:
- Integrated Fluid-Thermal-Structural Analysis

Facilities Operation and Development:
- Oxygen Enrichment and Alternate Mach Number Capability for the 8' HTT

Each highlight is accompanied by descriptive material.

Multidisciplinary Analysis and Optimization Branch

There are several major efforts planned for FY 83 which collectively, constitute a concentrated thrust to advance the state of the art of optimization and associated analysis. The focus for optimization algorithms is on development of techniques for optimization of structures under dynamic loads, and on implementation of the best selection of algorithms in the form of a computer program library (an update of the CONMIN program). In structural and multidisciplinary optimization, a major demonstration project--the Lockheed aircraft--will go from the analysis phase to the optimization phase. In design oriented analysis, completion of sensitivity implementation in a production level program (EAL) is planned. Combined thermal-structural-trajectory optimization will be initiated for STS TPS, and the possibility of actively controlling space structure thermal deformations will be investigated. The active control work will concentrate on tool building for multifunction control systems and on providing support for the DAST ARW-1 and ARW-2 experimental programs. In the flight loads area, most of the ARW-1 flight test program should be completed, the ARW-2 aircraft will move toward the flight test stage, and mission concepts for ARW-3 (or a modified ARW-2) will be formulated.

The plans/milestones marked on figure 20 are described in more detail in figure 58. Selected highlights of these milestones are listed below and are shown by figures 59 through 62.

Active Controls:
- DAST ARW-2 - Gust Loads Analysis

Design Oriented Analysis:
- Analytical Technique to Control Thermal Distortion of Space Structures by Applied Temperatures

Flight Loads:
- ARW-1R Schedule

Optimization and Applications:
- Advanced Modular Optimization Program

Each highlight is accompanied by descriptive material.

Unsteady Aerodynamics Branch

For FY 83, there will be an increasing level of activity in developing and applying computational finite-difference algorithms solving the nonlinear unsteady fluid flow equations. Strong emphasis will be given to determining the accuracy of each level of code and to the incorporation of realistic viscous boundary layer models. The application of these codes to the assessment of nonlinear aeroelastic stability will also be actively pursued.

In parallel with the development of computational methods, the unsteady pressure measurement program will continue to provide experimental data for code validation. To supplement the data already obtained from rigid oscillating models, unsteady pressure tests on an aeroelastic model will be obtained. Also, to provide data at flight Reynolds numbers and to define the importance of viscous boundary layer effects, tests at cryogenic temperatures will be conducted.

The plans/milestones marked on figure 27 are described in more detail in figure 63. Selected highlights of these milestones are listed below and are shown by figures 64 through 67.

Theory Development:
- Unsteady Full Potential Code for Loads Prediction and Aeroelastic Analysis

Aeroelastic Analysis:
- Assessment of 2-D Airfoil Transonic Flutter Characteristics

Unsteady Pressure Measurements:
- DAST ARW-2 TDT Test
- Oscillating Pressure Measurements on a 2-D Supercritical Wing in the 1/3 Meter Cryogenic Tunnel

Each highlight is accompanied by descriptive material.

Configuration Aeroelasticity Branch

For FY 83 the Configuration Aeroelasticity Branch (CAB) will continue its broadly based research program on dynamic and aeroelastic phenomena of aircraft and rotorcraft.

Although a large portion of this work is associated with tests in the Langley Transonic Dynamics Tunnel (TDT) with companion theoretical studies, flight test programs are included as well. Currently two major flight test programs are in progress. These are the Higher Harmonic Control (HHC) program which uses an active control system for rotorcraft vibration reduction and the Decoupler Pylon (DCP) program for passive flutter suppression of wings with external stores. Both of these programs had their beginning with successful tests in the TDT and advanced to the flight test phase to evaluate characteristics which cannot be properly studied in wind-tunnel experiments. Initial closed loop tests for the HHC system implemented on an OH-6A helicopter are expected to be accomplished in the coming year. The fabrication of decoupler pylons for installation on an F-16 airplane will be completed in the coming year also.

With respect to wind-tunnel tests in the TDT, research studies are planned for both rotorcraft and airplanes. The rotorcraft studies will use the aeroelastic rotor experimental system (ARES) and will focus on new rotor concepts such as the hingeless rotor. Airplane focused studies include such items as investigations of shock induced oscillations and aero/servo/elastic instabilities of forward swept wing configurations. In addition to research studies, two flutter clearance tests are planned for the F-16 airplane with new external stores.

Work will continue in the area of prediction of helicopter vibration characteristics by using finite element modeling procedures. The NASTRAN analysis/test correlation for the CH-47D airframe will be completed. Plans will be finalized for expanding this vibrations research to include other airframes and the incorporation of advanced technologies into vibration prediction methods.

The plans/milestones marked on figure 35 are described in more detail in figure 68. Selected highlights of these milestones are listed below and are shown by figures 69 through 72.

Aircraft Aeroelasticity:
- Decoupler Pylon Program
- Modifications to Upgrade the Langley TDT (Density Increase)

Rotorcraft Aeroelasticity:
- Aeroelastic Stability of Hingeless and Bearingless Rotors

Rotorcraft Vibrations:
- A National Capability to Analyze Vibration as Part of Helicopter Structural Design

Each highlight is accompanied by descriptive material.

CONCLUDING REMARKS

This publication documents the FY 1982 accomplishments, research and technology highlights, and FY 1983 plans for the Loads and Aeroelasticity Division. The accomplishments and plans are shown as they relate to the five year plan.

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LANGLEY RESEARCH CENTER

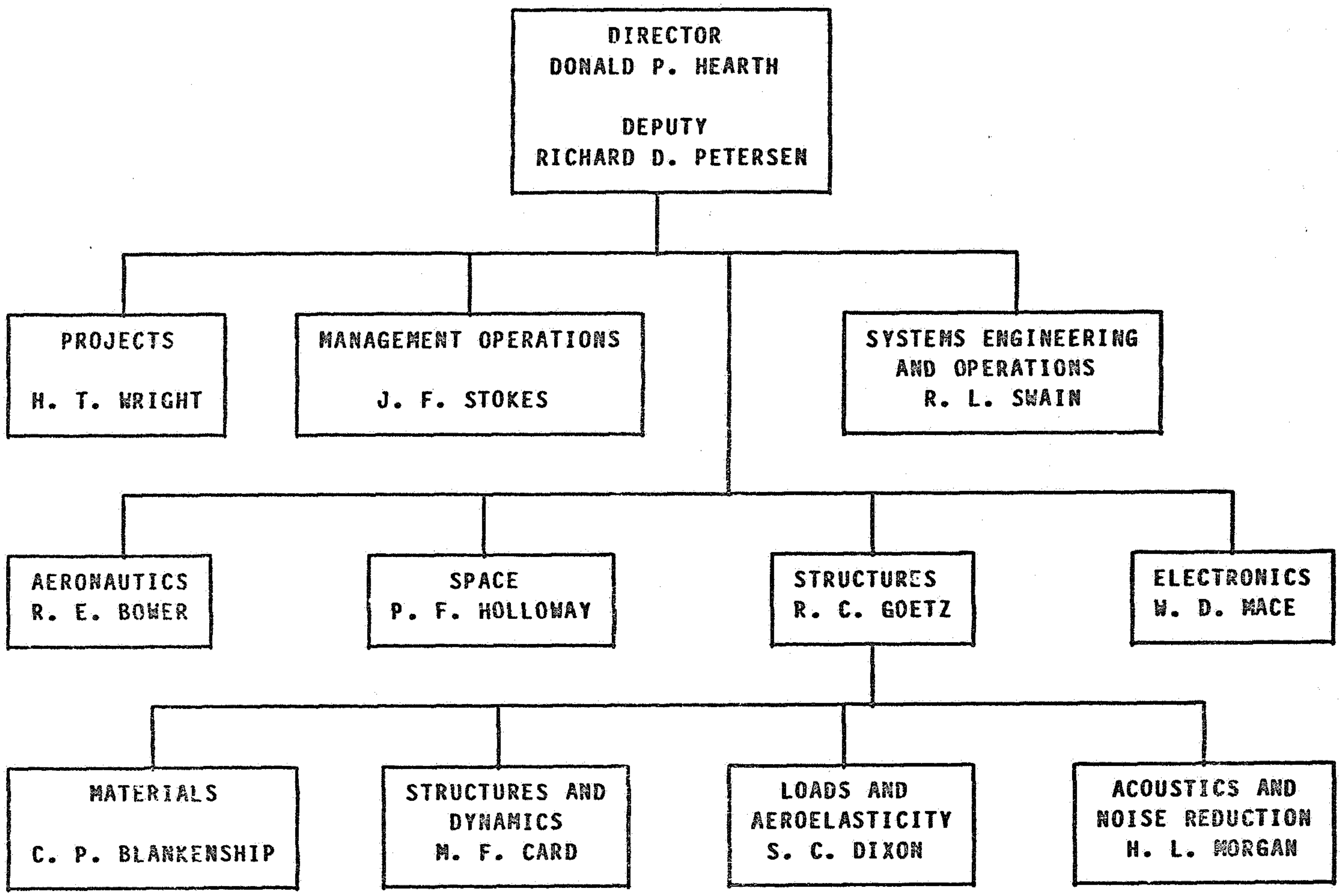

Figure 1.

LOADS AND AEROELASTICITY DIVISION

6

CHIEF:	SIDNEY C. DIXON
ASSISTANT CHIEF:	PERRY W. HANSON
CHIEF SCIENTIST:	E. CARSON YATES, JR.
TECHNICAL ASSISTANT:	JAMES E. GARDNER

AEROTHERMAL LOADS BRANCH	MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION BRANCH	UNSTEADY AERODYNAMICS BRANCH	CONFIGURATION AEROELASTICITY BRANCH
20	19	12	13 + 5A
HEAD: ALLAN WIETING ASST: NEALE KELLY	HEAD: JAROSLAW SOBIESKI ASST: IRVING ABEL	HEAD: JOHN EDWARDS	HEAD: ROBERT DOGGETT
- TPS CONCEPTS - THERMAL LOADS - INTEGRATED ANALYSIS - FACILITIES OPERATIONS & DEVELOPMENT	- ACTIVE CONTROLS - DESIGN ORIENTED ANALYSIS - FLIGHT LOADS - OPTIMIZATION AND APPLICATIONS	- THEORY DEVELOPMENT - NON-LINEAR AEROELASTIC ANALYSIS - UNSTEADY PRESSURE EXPERIMENTS	- AIRCRAFT AEROELASTICITY - ROTORCRAFT AEROELASTICITY - ROTORCRAFT VIBRATIONS

TOTAL NASA CS = 70
TOTAL ARMY CS = 5

Figure 2.

LOADS AND AEROELASTICITY DIVISION

LONG-RANGE THRUSTS

- CONTROL OF AEROELASTIC STABILITY AND RESPONSE
- COMPUTERIZED ANALYSIS AND SYNTHESIS (MULTIDISCIPLINARY OPTIMIZATION)
- THERMAL PROTECTION SYSTEMS FOR ADVANCED STS (CONCEPT DEVELOPMENT, AEROTHERMAL LOADS)
- LIGHTWEIGHT STRUCTURES FOR HIGH-SPEED VEHICLES (AEROTHERMAL LOADS)
- DEVELOPMENT OF ADVANCED STS (AEROTHERMAL LOADS)
- DEVELOPMENT OF LARGE SPACE STRUCTURES (THERMAL LOADS)

Figure 3.

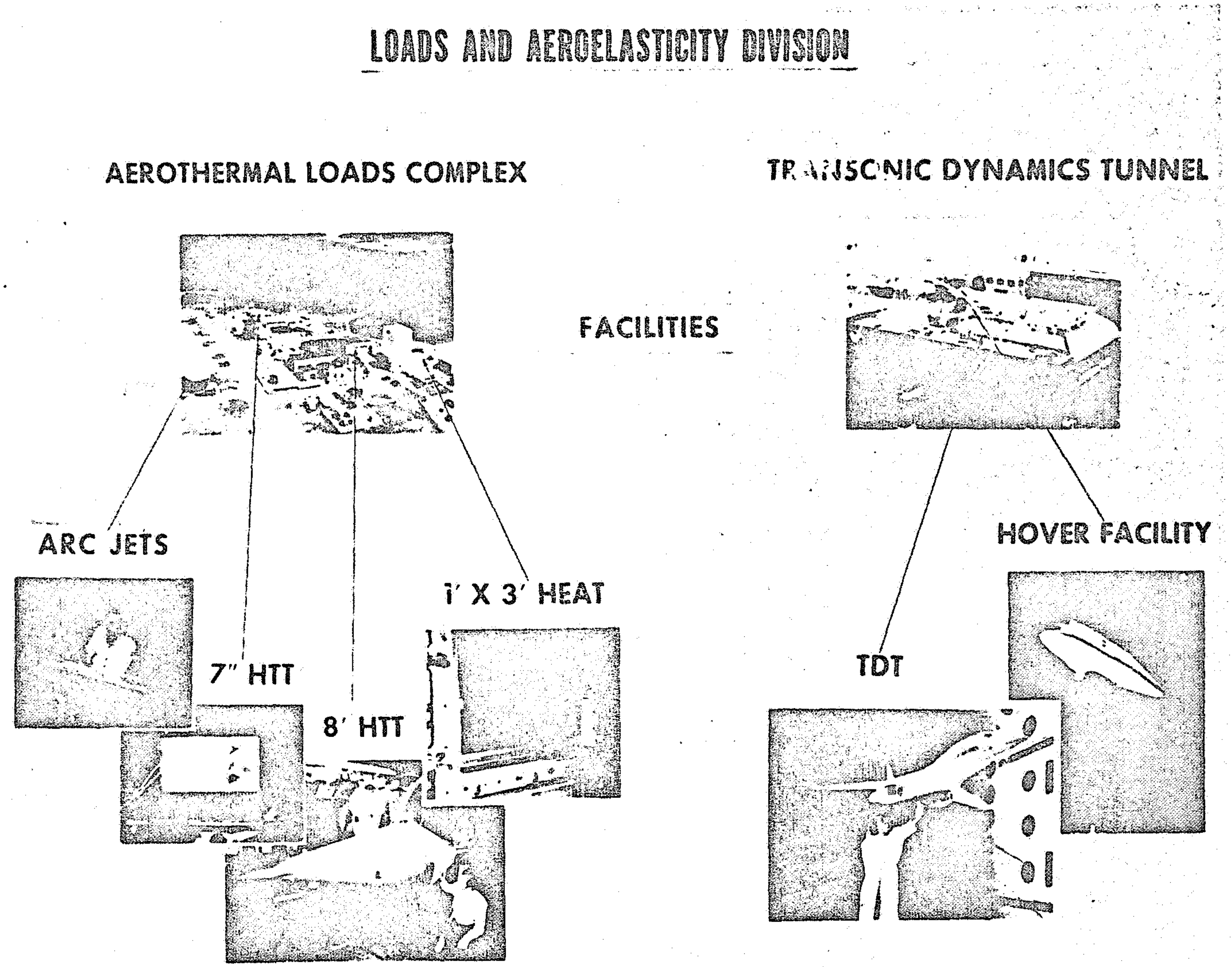
LOADS AND AEROELASTICITY DIVISION
AEROTHERMAL LOADS COMPLEX
FACILITIES
TR.NSONIC DYNAMICS TUNNEL
ARC JETS
7" HTT
8' HTT
1' X 3' HEAT
TDT
HOVER FACILITY

Figure 4.

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NASA
L-82-1,592

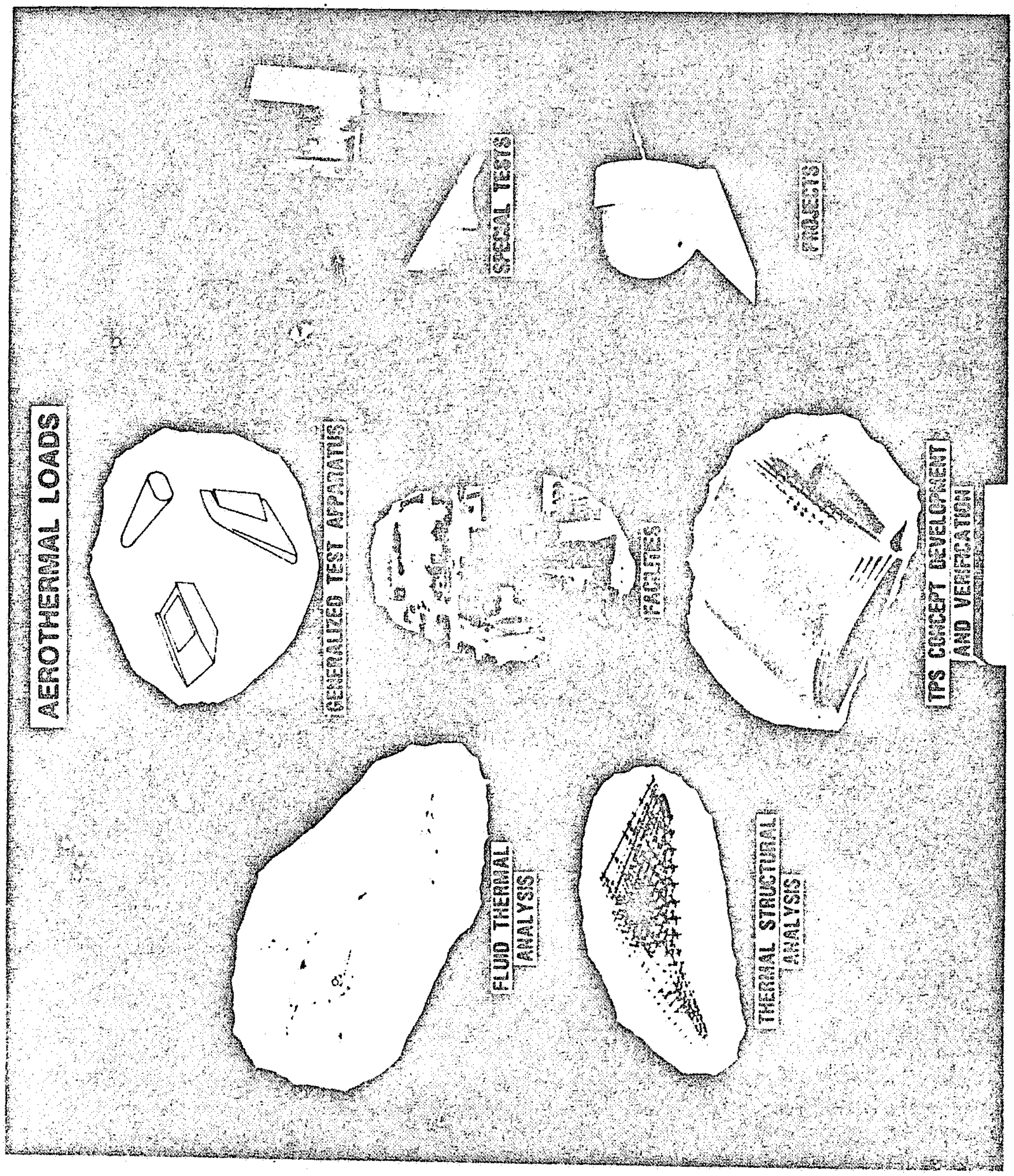


Figure 5.

AEROTHERMAL LOADS
5 YEAR PLAN

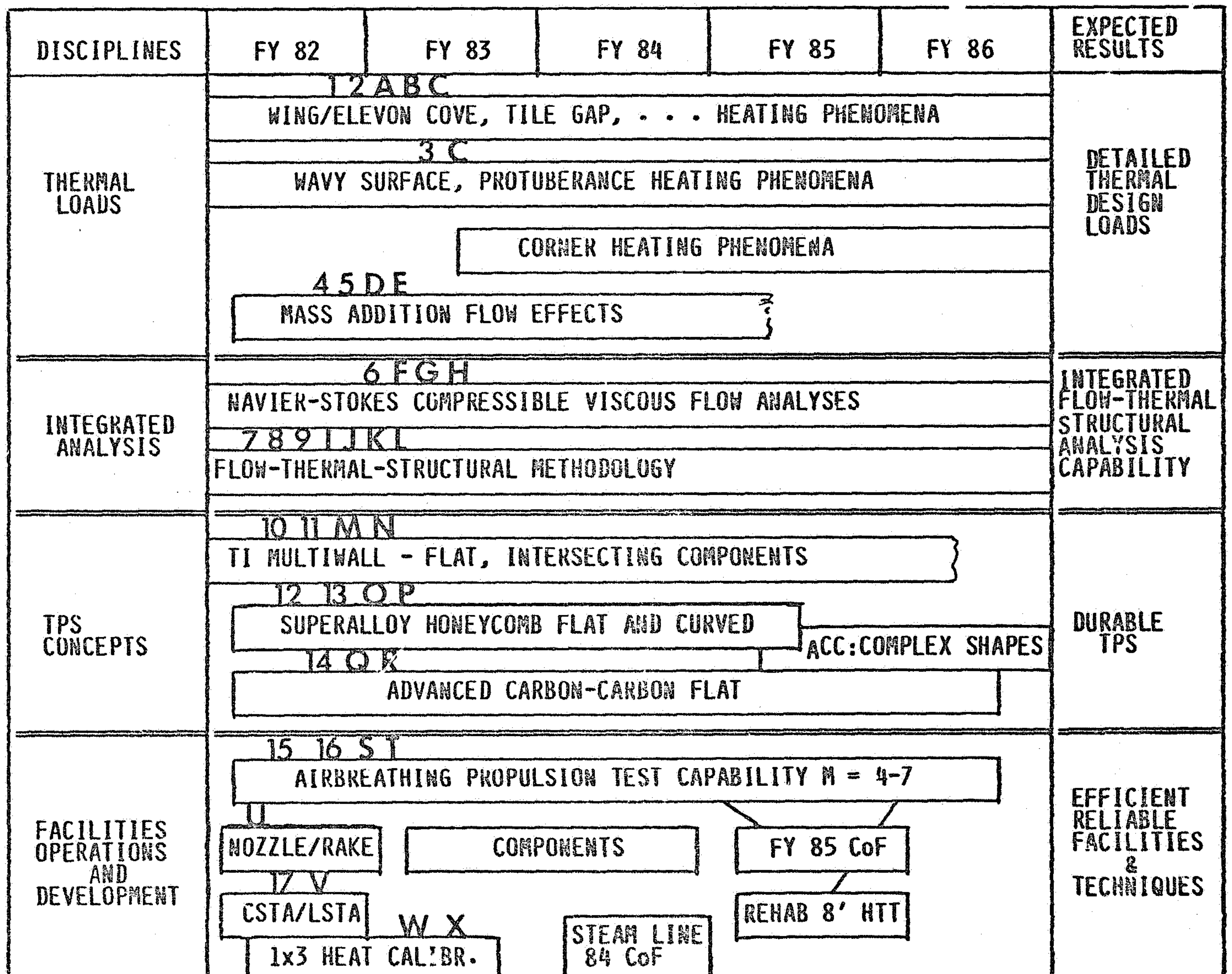


Figure 6.

AEROTHERMAL LOADS

FY 82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP	MILESTONE/ACCOMPLISHMENT	SIGNIFICANCE	STATUS
1	506-53-63	DOCUMENT WING-ELEVON COVE HEATING TESTS BY 12/81	EFFECT OF SEPARATED FLOW DEFINED	DATE NOT MET SEE FY 83 MILESTONES A
2	506-53-63	ANALYZE GAP HEATING RESULTS INCLUDING FLOW ANGULARITY EFFECTS BY 10/82	FLOW ANGULARITY EFFECTS ON LOCAL AND TOTAL TILE HEATING DEFINED	TESTS COMPLETED DATA REDUCED PAPER IN PREP. SEE B
3	506-53-63	DESIGN AND FAB WAVY SURFACE MODEL TYPICAL OF THERMALLY BOWED TPS	EFFECT OF BOWED SURFACE ON AEROTHERMAL LOADS	DESIGN COMPLETE FAB STARTED
4	506-53-63	DOCUMENT GAS JET NOSE TIP DATA OBTAINED ON DEFENSE NUCLEAR AGENCY CONICAL MODEL IN 8' HTT BY 3/82	EFFECTIVENESS OF DNA NOSE TIP CONCEPT EVALUATED	COOPERATIVE DATA ANALYSIS WITH PDA, WAITING FOR PDA RESULTS SEE D
5	506-53-63	TESTS OF 12-1/2° FILM COOLED CONE IN 8' HTT BY 2/82	COOLING EFFECTIVENESS OF TWO CONCEPTS (INCLUDING DOD TIP) DEFINED	TEST IN PROGRESS SEE E

Figure 7(a).

AEROTHERMAL LOADS

FY 82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP	MILESTONE/ACCOMPLISHMENT	SIGNIFICANCE	STATUS
6	506-53-63	INITIATE FULL NAVIER-STOKES ANALYSIS OF FLOW OVER WAVY SURFACE (THERMALLY BOWED TPS) BY 11/81	EFFECT OF BOWING ON FLOW AND HEATING DEFINED, CRITICAL PARAMETERS AND INFLUENCE DEFINED	MODEL & ALGORITHM DEVELOPED, SEE F
7	506-53-53	INITIATE GRANT TO ODU (THORNTON) FOR INTEGRATED THERMAL-STRUCTURAL ANALYSIS BY 1/82	CONTINUATION OF SIGNIFICANT EFFORT	POTENTIAL OF APPROACH DEMO. THROUGH APPLICATION OF 1D & 2D ELEMENTS, SEE I
8	506-53-53	INITIATE GRANT WITH U. OF WASHINGTON (EMERY) FOR RADIATION VIEWFACTORS BY 2/82	CONTINUATION OF SIGNIFICANT EFFORT	PROTOTYPE VIEW FACTOR CODE DEVELOPED AND DEMONSTRATED ON LDEF, SEE J
9	506-53-53	DEVELOP PROTOTYPE INTEGRATED 2-D THERMAL FINITE ELEMENTS BY 6/82	EXTENSION OF PROVEN 1D METHODOLOGY TO BROADER PRACTICAL APPLICATIONS	PROTOTYPE MEMBRANE ELEMENT COMPLETED REPORT PHD THESIS SDM CONFERENCE SEE I

Figure 7(b).

AEROTHERMAL LOADS

FY 82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP	MILESTONE/ACCOMPLISHMENT	SIGNIFICANCE	STATUS
10	506-53-33	COMPLETE METALLIC TPS OEX (TITANIUM MULTIWALL) QUALIFICATION TESTING BY 4/82	PROVIDE QUALIFIED TPS FOR OEX FLIGHT TESTS	QUALIFICATION MODELS TO BE DELIVERED 10/82 TEST SCHEDULED 3/83
11	506-53-33	INITIATE ACOUSTIC TESTS OF GR/PI PANEL WITH DIRECT BOND RSI TILES	DEMONSTRATE CONCEPT DURABILITY TO SHUTTLE ASCENT ACOUSTICS	50 EXPOSURES TO SHUTTLE ASCENT LOADS COMPLETED
12	506-53-33	COMPLETE 8' HTT TESTS OF SUPERALLOY PREPACKAGED TPS BY 8/82	PROVIDE VERIFIED DURABLE TPS FOR 1000°F TO 2000°F TEMPERATURE RANGE	DATE NOT MET SEE N
13	506-53-33	INITIATE CONTRACTUAL STUDY FOR TPS FOR CURVED AND INTERSECTING SURFACES BY 3/82 <u>6/82</u>	DEMONSTRATE METALLIC TPS FOR CURVED SURFACES	CONTRACT AWARDED SEE O AND P

Figure 7(c).

AEROTHERMAL LOADS

FY 82 MILESTONES /ACCOMPLISHMENTS

NO.	RTOP	MILESTONE/ACCOMPLISHMENT	SIGNIFICANCE	STATUS
14	506-53-33	INITIATE CONTRACTUAL STUDY OF FLAT ACC TPS BY 1/82	PROVIDE VERIFIED DURABLE TPS FOR 1800°F + TEMPERATURE RANGE	CONTRACT AWARDED SEE Q AND R
15	505-33-73	COMPLETE EVALUATION OF 1ST TWO INSERT CONCEPTS BY 1/82	ALTERNATE MACH NO. CAPABILITY	VIABLE CONCEPT DEMONSTRATED SEE T
16	505-33-73	COMPLETE EVALUATION OF O_2 ENRICHMENT SCHEME	PROPULSION TEST CAPABILITY DEMONSTRATED	DESIGN FOR 7" HTT COMPLETE, PROCUREMENTS OUT, MODS. INITIATED SEE S
17	506-53-63	DEFINE FLOW FIELD FOR CSTA IN 8' HTT BY 10/82	3D FLOW FIELD DEFINED FOR GENERAL PURPOSE TEST APPARATUS	INSTRUMENTED TEST DATE NOT MET SEE V

SECOND GENERATION TITANIUM MULTIWALL TPS TILE SUCCESSFULLY FABRICATED

John L. Shideler
Aerothermal Loads Branch
Extension 3423

RTOP 506-53-33

Research Objective

The objective of this program is to develop a durable Thermal Protection System (TPS) for Future Space Transportation Systems (FSTS) for surfaces which experience maximum temperatures between 700°F and 1200°F.

Approach

Design, fabricate, and test titanium multiwall tiles to assess applicability for use as TPS for FSTS.

Accomplishment Description

A second generation titanium multiwall thermal protection tile has been successfully fabricated as part of the OEX metallic thermal protection system program. The tile, which was fabricated by Rohr Industries under contract NAS1-15646, incorporates modifications to overcome deficiencies identified in tests of the first generation tiles. In the study for alternate TPS for the Space Shuttle (Contract NAS1-16302), the titanium multiwall concept was selected for application in the 700°F to 1000°F temperature range. The second generation tile, like the first generation tile, is 0.7" thick and consists of four dimpled 0.003" sheets and three flat 0.0015" sheets sandwiched between a 0.003" inner face sheet and a 0.004" outer face sheet. The mass of the tile is 0.75 lbm/ft^2 and is competitive with the mass of the LI-900 RSI. The modifications include: the use of 90 degree, instead of 30 degree scarfed, side closures to improve thermal expansion compatibility between adjacent tiles and to reduce fabrication problems; substitution of the stronger Ti 6Al - 2Sn - 4Zr - 2Mo alloy for Ti 6Al - 4V alloy in the higher temperature layers; and slightly larger contact nodes to improve strength of the tiles. Developmental tests by the contractor indicate that the new tiles meet or exceed the design goals. The flatwise tension strength of the tiles has been increased by approximately 55 percent without any significant increases in thermal conductivity or mass. The second generation tile shown in the figure has been tested at 1000°F to a uniform outward pressure of 3 psi (3 times the design pressure) with no evidence of damage.

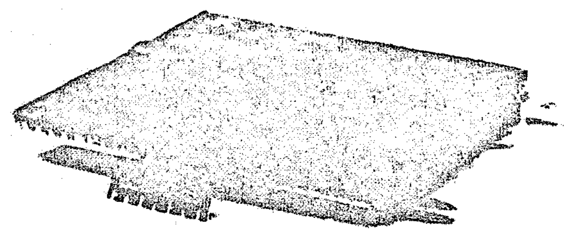
Future Plans

A 17.5 square foot array plus four individual tiles of the improved design are currently being fabricated for environmental tests at the Langley Research Center. The tests will be conducted as part of the base R&T program.

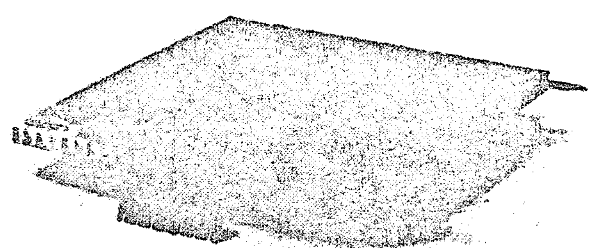
Figure 8(a).

SECOND GENERATION TITANIUM MULTIWALL
TILE SUCCESSFULLY FABRICATED

TOP VIEW



BOTTOM VIEW



- MODIFIED DESIGN MEETS OR EXCEEDS DESIGN GOALS (UP TO 1000°F)
- 1 x 1 FOOT TILE STATIC TESTED TO 3 PSI AT 1000°F WITHOUT FAILURE
- 3.5 x 5 FOOT ARRAY FOR AEROTHERMAL TESTS TO BE DELIVERED BY MAY 1982

Figure 8(b).

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SUPERALLOY HONEYCOMB PREPACKAGED TPS TILE SUCCESSFULLY FABRICATED

John L. Shideler
Aerothermal Loads Branch
Extension 3423

RTOP 506-53-33

Research Objective

The objective of the program is to develop a durable Thermal Protection System (TPS) for Future Space Transportation System (FSTS) for surface which experience maximum temperature between 1200°F and 2000°F.

Approach

Design, fabricate, and test superalloy honeycomb prepackaged tiles to assess applicability for use as TPS for FSTS.

Accomplishment Description

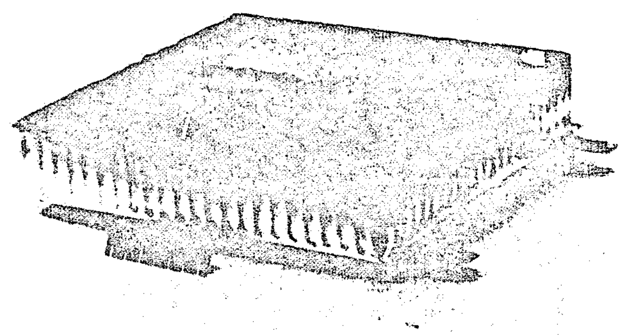
A 12" by 12" superalloy honeycomb prepackaged thermal protection tile has been successfully fabricated by Rohr Industries under Contract NAS1-15696. The tile which is an outgrowth of, and is compatible with, titanium multiwall tiles is intended for application in the 1200°F to 2000°F temperature range. As shown by the sketch, the tile consists of an Inconel 617 honeycomb hot surface panel, a titanium honeycomb cold surface panel, and beaded Inconel 617 side closures which encapsulate layered fibrous insulation. The Inconel honeycomb has 0.005 inch thick face sheets and a 0.28 inch deep 3/16 inch square-cell core; the titanium honeycomb has .006 inch thick face sheets (with the inner face sheet chem milled to .003 inch in the central region) and 0.17 inch deep 3/16 inch square-cell core; and the side closures are of .003 inch foil. All core is fabricated from 0.0015 inch foil. The complete tile, which is fabricated in a three step operation using a proprietary joining process, is 2.35 inches thick and weighs 2.2 pounds including attachment clips. Developmental tests by the contractor indicate that superalloy tiles meet or exceed the design goals. The tile shown in the figure has been exposed to radiation heating that produced a temperature of 2000°F on the hot surface and 400°F on the backside, and has been tested to a uniform outward pressure of 3.6 psi (1.8 times the design pressure) at 1000°F (100°F backside temperature). At that pressure the tile developed a leak at the corner in the joint between the Inconel side closure and the titanium face sheet, which prevented further pressure tests. The existence of the leak identified the need for a minor design change before fabricating additional test tiles. The leak will be repaired, and the panel will be retested to destruction.

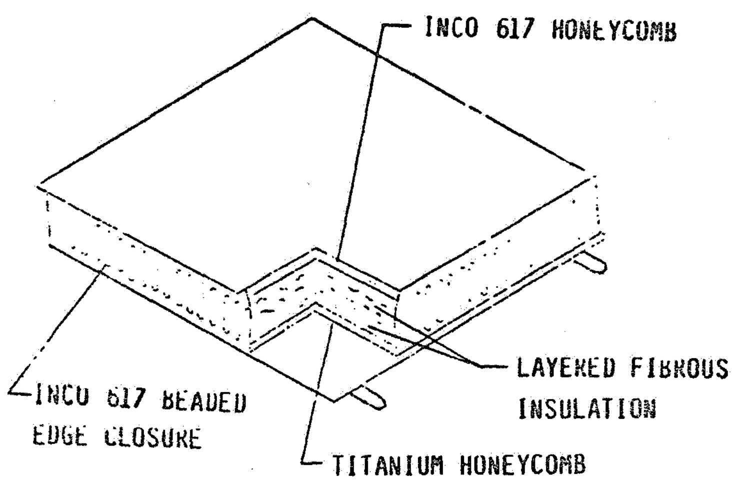
Future Plans

A 17.5 square foot array plus five individual superalloy honeycomb prepackaged tiles are currently being fabricated for environmental tests at the Langley Research Center.

Figure 9(a).

SUPERALLOY HONEYCOMB PREPACKAGED TPS
SUCCESSFULLY FABRICATED





- DESIGN MEETS OR EXCEEDS DESIGN GOALS (UP TO 2000°F)
- 1 x 1 FOOT PANEL STATIC TESTED TO 3.6 PSI AT 1000°F WITHOUT FAILURE
- 3.5 x 5 FOOT ARRAY FOR AEROTHERMAL TESTS TO BE DELIVERED MAY 1982

Figure 9(b).

LaRC TESTS IN 20 MW AAT CERTIFY FRCI-12 FOR SINGLE MISSION

Robert F. Mayo
Aerothermal Loads Branch
Extension 3894

RTOP 506-53-33

Research Objectives

The FRCI-12 (Fibrous Refractory Composite Insulation, 12 lb/ft^3 nominal density) has been proposed as a replacement thermal protection system tile for LI-2200 (Lockheed Insulation, 22 lb/ft^3) on OV-103, OV-102 and OV-099. FRCI-12 has superior mechanical properties at reduced mass than LI-2200. Since the LI-2200 was certified for a single mission prior to STS-1 at LaRC, the Manager, Orbiter Project, JSC, requested the certification tests for FRCI-12 be conducted in the NASA/Langley 20 MW Aerothermal Arc Tunnel (AAT). The tests would permit direct comparison of the performance of FRCI-12 to LI-2200. The test articles represented the three most critical high pressure gradient, high temperature areas on the Orbiter; specifically the chine, the nose gear door, and the elevon/body flaps. The certification tests are based on off-nominal (nominal plus root sum square uncertainties) flight conditions. Hence, the tiles are certified for at least one mission at the worst flight environment. The actual tiles are recertified on a flight by flight basis with the ground tests serving as datum.

Approach

The original LI-2200 test articles were duplicated by Rockwell International with replicate FRCI-12 tiles. Additionally, the tunnel parameters used for the corresponding LI-2200 tests were repeated for the FRCI-12 tests.

Accomplishment Description

The FRCI-12 tiles demonstrated at least a single mission capability in all tests. The LI-2200 tests had also demonstrated at least a single mission capability. However, the FRCI-12 appears to have a greater amount of surface shrinkage. The gaps appeared to grow at a faster rate and the forward facing steps shrank faster. The initial high temperature areas caused by forward facing steps operate at a lower temperature upon shrinkage of the step. Therefore, shrinkage of forward facing steps is somewhat beneficial. The shrinkage of the FRCI-12 encountered in these tests would not be as great in the actual flight case. The off-nominal flight condition results in the tiles operating about 200°F higher during the certification testing than during actual nominal flight conditions. The amount of shrinkage significantly increases above 2300°F. Therefore, at the lower temperatures enountered during a nominal flight ($T_{max} < 2400°F$) the shrinkage would be reduced. The three test articles and associated test data have been forwarded to RI for detailed inspection and further analysis.

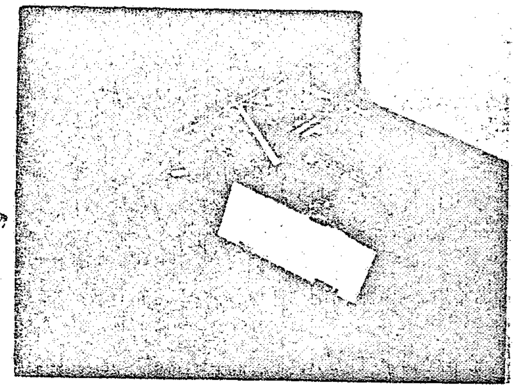
Future Plans

Any requirements for additional certification testing of the FRCI-12 will be determined after the results of the more detailed inspection and analysis of the test data from these three test articles by the prime contractor (RI).

Figure 10(a).

LaRC TESTS CERTIFY FRCI-12 FOR SINGLE MISSION

- CERTIFIED IN 20 MW AAT FOR SINGLE MISSION
  - LI-2200 FOR STS-1
  - FRCI-12 FOR REPLACEMENT OF LI-2200
- FRCI-12 TEST AREAS - HIGH PRESSURE AND HIGH TEMPERATURES
  - CHINE
  - NOSE GEAR DOOR
  - ELEVON/BODY FLAP



PRE-TEST

POST TEST

Figure 10(b).

GRAPHITE/POLYIMIDE PANEL WITH DIRECT BOND RSI TILES SURVIVES SIMULATED SHUTTLE ASCENT ACOUSTICS

Richard W. Tyson
Aerothermal Loads Branch
Extension 3158

RTOP 506-53-33

Research Objectives

The CASTS program (Composites for Advanced Space Transportation Systems) has shown that significant mass reductions in the Space Shuttle structure can be realized through the use of high temperature graphite/polyimide composite components because of 1) the higher strength to weight ratio of the composite relative to the basic aluminum structure currently used; 2) the higher temperature capability of the composites which reduces insulation requirements; and 3) the improved thermal expansion compatibility between the ceramic reusable surface insulation (RSI) and the composite substrate which permits elimination of the strain isolation pad. The objectives of the acoustic fatigue tests of direct bond RSI tile on graphite/polyimide structures are 1) verify the primary-structure acoustic fatigue life (100 Shuttle missions), 2) demonstrate the integrity of selected regions of the direct-bond TPS, and 3) verify the analytically predictable corner panel root mean square (RMS) strain and frequency of a representative specimen of the advanced structural system.

Approach

As illustrated, a 20- by 40-inch graphite/polyimide honeycomb panel with an array of 13 directly bonded RSI tiles, has been exposed to the high energy noise field of the 8' HTT. This panel is representative of a section of the Shuttle body flap and has been tested as a secondary test to the scheduled activity of the tunnel. As shown, the frequency content of the wind tunnel noise is similar to that of the Shuttle. The intensity can be adjusted by repositioning the test specimen in the tunnel noise field.

Accomplishment Description

Over the past 14 months the panel has been exposed to 38 minutes of tunnel noise at an overall sound pressure level (OASPL) of approximately 154 dB which simulates the total aerodynamic acoustic load for 100 Shuttle missions and an additional 3 minutes at 161 dB OASPL with no evidence of structural degradation. As illustrated by the figure the panel response peaks at approximately 260 Hertz, which corresponds favorably with the predicted fundamental frequency of 297 Hertz, producing acceleration forces of approximately 100 g's near the center of the panel.

Future Plans

The panel has been repositioned to increase the noise exposure to 161 dB OASPL for 34 min. to simulate the higher dB levels experienced during liftoff. Subsequently the panel will be repositioned to increase the intensity to 165 dB OASPL, which corresponds to the design level.

Figure 11(a).

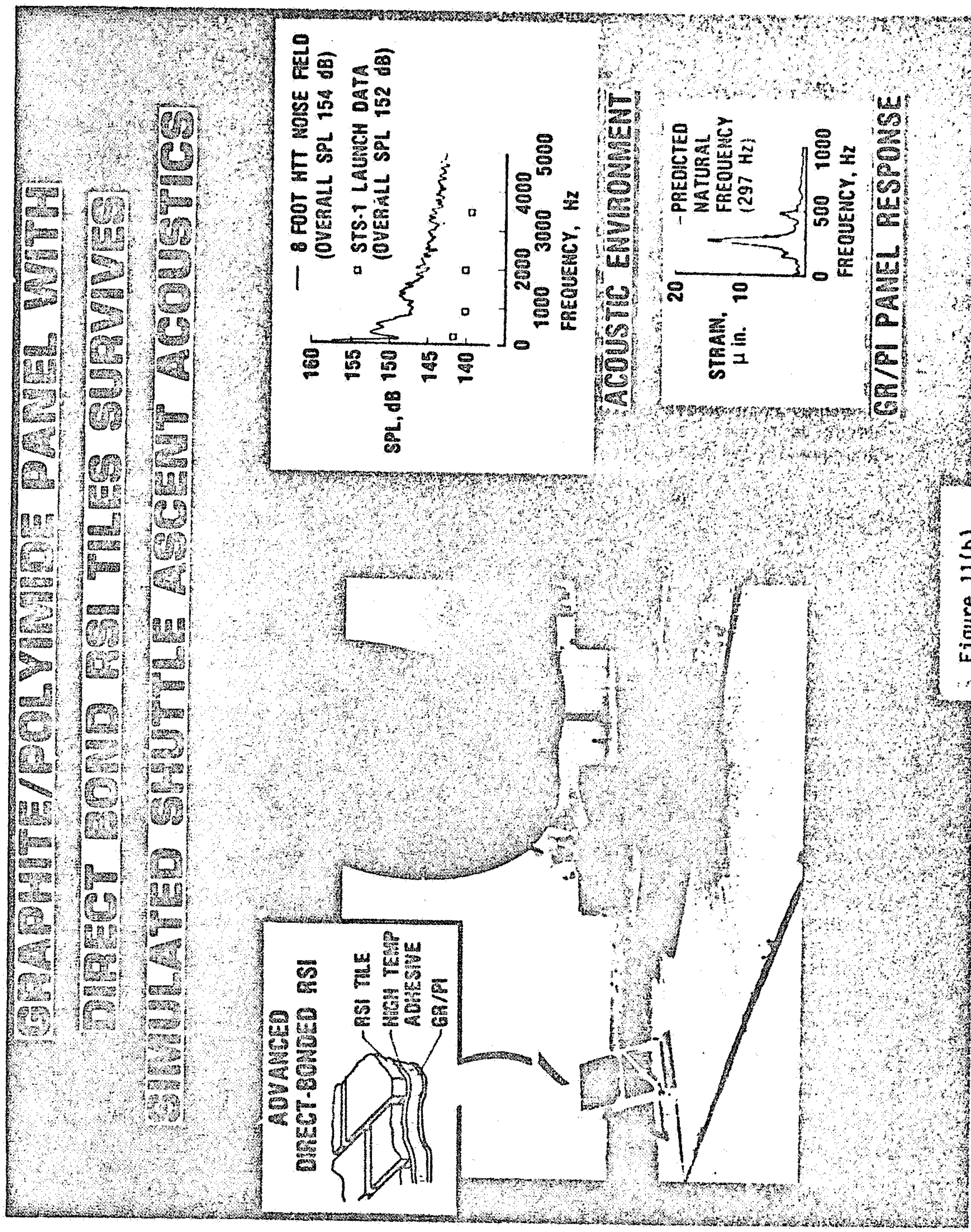

GRAPHITE/POLYIMIDE PANEL WITH
DIRECT BOND RSI TILES SURVIVES
SIMULATED SHUTTLE ASCENT ACOUSTICS
ADVANCED DIRECT-BONDED RSI
RSI TILE
HIGH TEMP ADHESIVE
GR/PI
— 8 FOOT HTT NOISE FIELD (OVERALL SPL 154 dB)
□ STS-1 LAUNCH DATA (OVERALL SPL 152 dB)
SPL, dB
160
155
150
145
140
0
1000
2000
3000
4000
5000
FREQUENCY, Hz
ACOUSTIC ENVIRONMENT
PREDICTED NATURAL FREQUENCY (297 Hz)
STRAIN, μ in.
20
10
0
500
1000
FREQUENCY, Hz
GR/PI PANEL RESPONSE

Figure 11(b).

FLOW ANGULARITY EFFECTS ON TILE/GAP IMPINGEMENT HEATING

Don E. Avery
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Extension 3168

RTOP 506-53-63

Research Objectives

Previous aerothermal tests on Shuttle type tiles in the LaRC 8' HTT identified the effects of boundary layer and gap geometry on the impingement heating rate on the tile's forward face at the end of the longitudinal gap aligned with the flow ("T" gap). However, more detailed heating is needed to define the overall tile heating at various flow angles for Shuttle tile certification. The present study extends the previous effort to include the effect of impingement heating on the upstream tile corner due to flow angularity with respect to the longitudinal gap. Flow angles include 0, 15, 30, 45, and 60 degrees. In addition, the effects of boundary layer state and thickness, Reynolds number, and gap width on localized heating which affects tile coating and overall heating which affects the structural integrity are being analyzed.

Approach

In order to obtain the desired heating detail, a highly instrumented thin-wall metallic tile was tested in the 8' HTT as shown in the tile array in the figure.

Accomplishment Description

Preliminary results indicating flow angularity effects for laminar and turbulent boundary layers on the peak impingement heating for a gap width of 0.070" are shown in the figures. The heating rates are nondimensionalized to the theoretical flat plate value. For laminar flow, the impingement heating at the upstream corner and at the end of the "T" gap are relatively constant for $\Lambda < 45°$. For $\Lambda > 45°$, the increased heating probably reflects increasing flow in the uninterrupted gap as the gap becomes more closely aligned with the flow. For turbulent flow the behavior of the heating at the corner is very similar to that of the laminar flow. However, impingement heating at the end of the "T" gap is significantly higher at $\Lambda = 0°$ but reduces with flow angle. As reported with previous tests for $W < 0.070$ inches, laminar flow over a tile heating is primarily three-dimensional at the "T" junction. Therefore, the turbulent boundary layer allows a larger impingement heating for flow angles near zero.

Future Plans

This data will allow the effect of flow angularity to be incorporated into an empirical relationship, developed from previous tests, which accurately predict the effects of gap geometry over a range of boundary layer conditions.

Figure 12(a).

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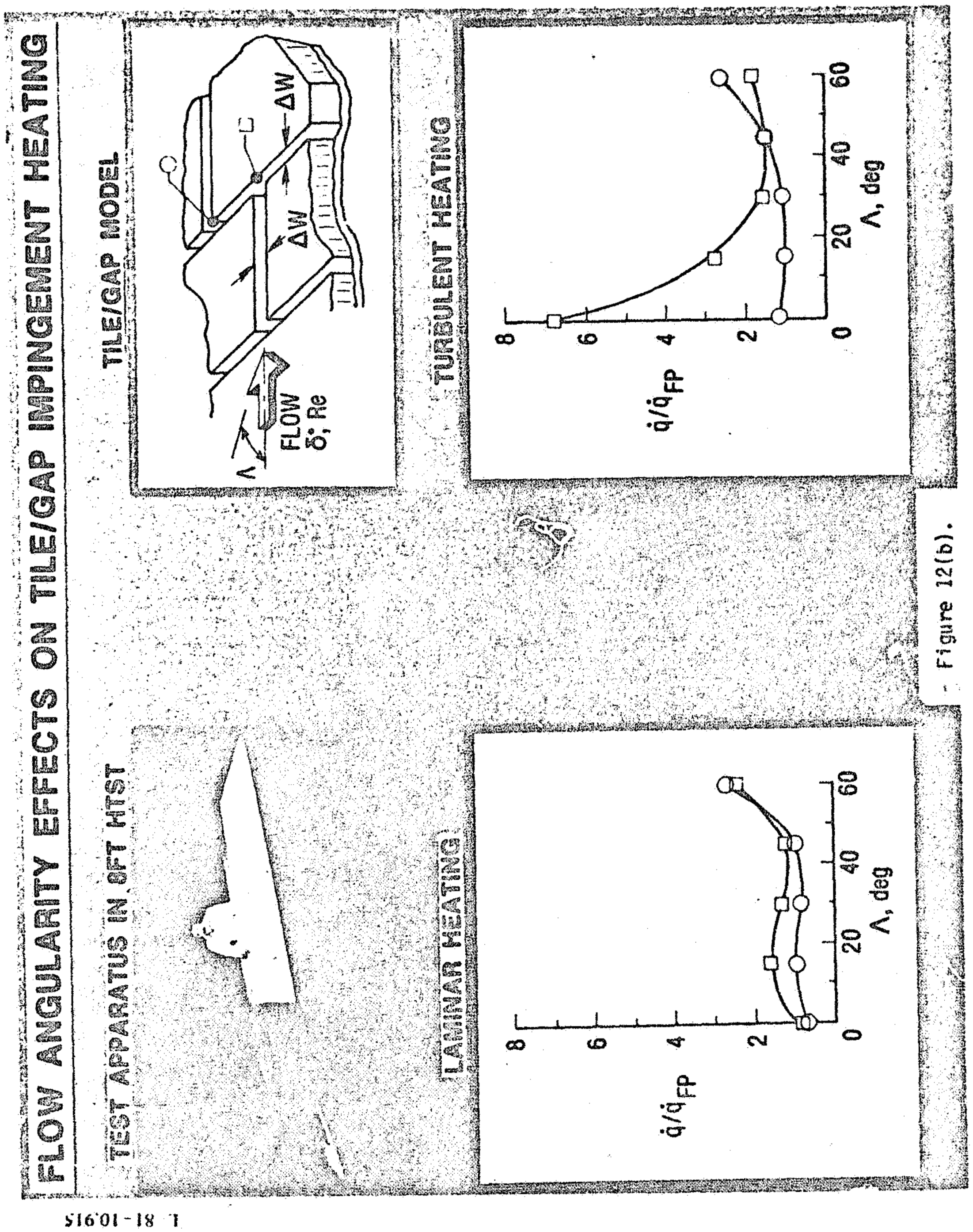

Figure 12(b).

HEAT TRANSFER MODEL USING NEW FABRICATION TECHNIQUE TESTED IN 8' HTT

Don E. Avery
Aerothermal Loads Branch
Extension 3168

RTOP 506-53-63

Research Objectives

The ALB has been investigating tile gap heating phenomena to identify the effects of gap geometry and flow parameters on both local and integrated heating. Metallic thin wall arrays have been used to obtain local heat fluxes. The high density instrumentation requirements to obtain detailed distributions in the localized impingement heating zones eliminated conventional model fabrication methods. Consequently, fabrication by an electroless nickel plating technique developed under a Johnson Space Center contract was selected. Although this technique has been employed to fabricate small models, this effort to fabricate a 6 by 6 by 2.5 inch tile shell 0.025 inches thick for heat transfer tests represented a significant extension of the technology. This process is not limited to any particular geometry and results in a seamless thin wall heat transfer model which uses a single wire thermocouple to attain local "cold wall" heating rates.

Approach

The new fabrication technique requires 10 steps and several precision molds: The first six steps generate a cerrotru mandrel which is plated with a nickel alloy, Niculoy 22, to one-half the desired tile wall thickness. The thermocouple wires are clipped and polished flush with the surface prior to the final plating. The cerrotru mandrel is removed by melting.

Accomplishment Description

Two heat transfer models were fabricated and one was installed in the center of an array of other simulated Shuttle tiles and tested in the 8' HTT. The effects of boundary layer state and thickness, flow angle, gap width and tile step height on localized and overall heating are being analyzed. Seventy-three percent of the 40 tests were completed before both models were damaged beyond repair. The model failures resulted from thermal shock induced by the tests, which also resulted in the 500°F material temperature limit being exceeded. In addition, the brittle nature of the material and the structural weakness of the flat-sided configuration was degraded and eventually could not withstand the nominal pressure loading associated with the tests and failed. The test program and model are considered to be successful and this fabrication technique is a viable option for highly detailed models, especially configurations that do not carry significant bending loads.

Future Plans

Additional work is required to optimize flat configurations. A possible solution would be to form the model on a low thermal conductivity material which could also provide structural support.

Figure 13(a).

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NASA
L-81-10,914

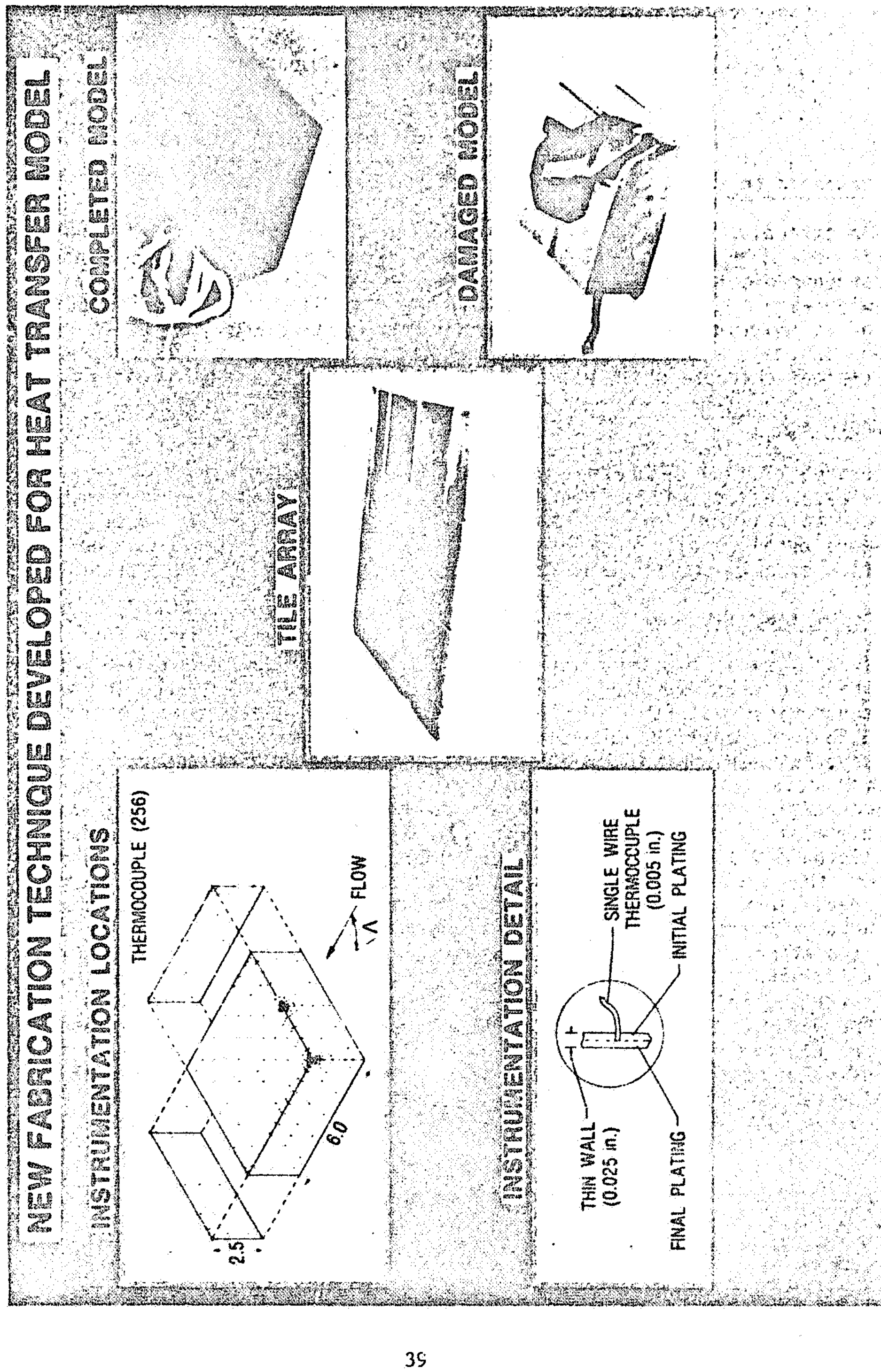

Figure 13(b).

UNSEALED WING-ELEVON COVE HEATING CHARACTERISTICS AT $M = 6.8$
FOR SEPARATED FLOW ON WING

William D. Deveikis
Aerothermal Loads Branch
Extension 2325

RTOP 506-53-63

Research Objectives

An extensive investigation was conducted at a free-stream Mach number of 6.8 in the Langley 8' HTT to define effects of laminar flow separation on aerodynamic heating in a leaking cove of a full-scale representation of the wing-elevon juncture on the Space Shuttle Orbiter. The investigation is part of an on-going effort by the Aerothermal Loads Branch to collect information on the nature of cove flow for use in formulating a method for predicting the thermal response of an unsealed cove structure for winged reentry vehicles.

Approach

Extent of flow separation was varied by cove seal leak gap (0 to 0.5 inch), elevon deflection (15° to 35°), and free-stream unit Reynolds number (0.4×10^6 to 1.4×10^6 per ft.). Pressure and cold-wall heating-rate distributions were obtained along the wing, cove, and elevon surfaces shown on the simplified cross-sectional view at the upper right for an angle of attack of 5°.

Accomplishment Description

Three typical heating-rate distributions present heating rates referenced to the wing value for laminar attached flow at the cove entrance for various flow separation distances obtained with 12.5- and 50-percent leaks (0.06- and 0.25-inch gaps) and elevon deflections of 15° and 2[illegible]° at a free-stream unit Reynolds number of 0.4×10^6 per ft. When laminar flow separation occurs near the cove entrance, wing heating rates under the separated boundary layer decrease sharply from equivalent attached-flow values, and cove heating rates diminish from the cove entrance by an order of magnitude. Increasing the elevon deflection angle extends the length of flow separation, and, as shown by the rising wing heating rates, the separated laminar boundary layer transitions to turbulent flow ahead of the cove entrance. Consequently, cove heating rates are an order-of-magnitude greater than for purely laminar flow separation at the same cove seal leak gap. However, if the leak gap increases sufficiently, boundary-layer suction can force the separated boundary layer to reattach, in which event cove heating rates approximate the level of heating for laminar flow separation. As indicated, the agreement between test data and calculated values is good. Calculations for cove heating were obtained using a simple 1D math model which assumed laminar developing channel flow. Scatter of cove data about the predicted distribution results from abrupt changes in flow path and cove area which are not accounted for by the constant-area channel-flow math model.

Future Plans

Wind-tunnel investigations will be conducted to study 3-dimensional flow effects on cove aerothermal environment using the Lifting Surface Test Apparatus (LSTA) to simulate a swept wing with control surfaces.

Figure 14(a).

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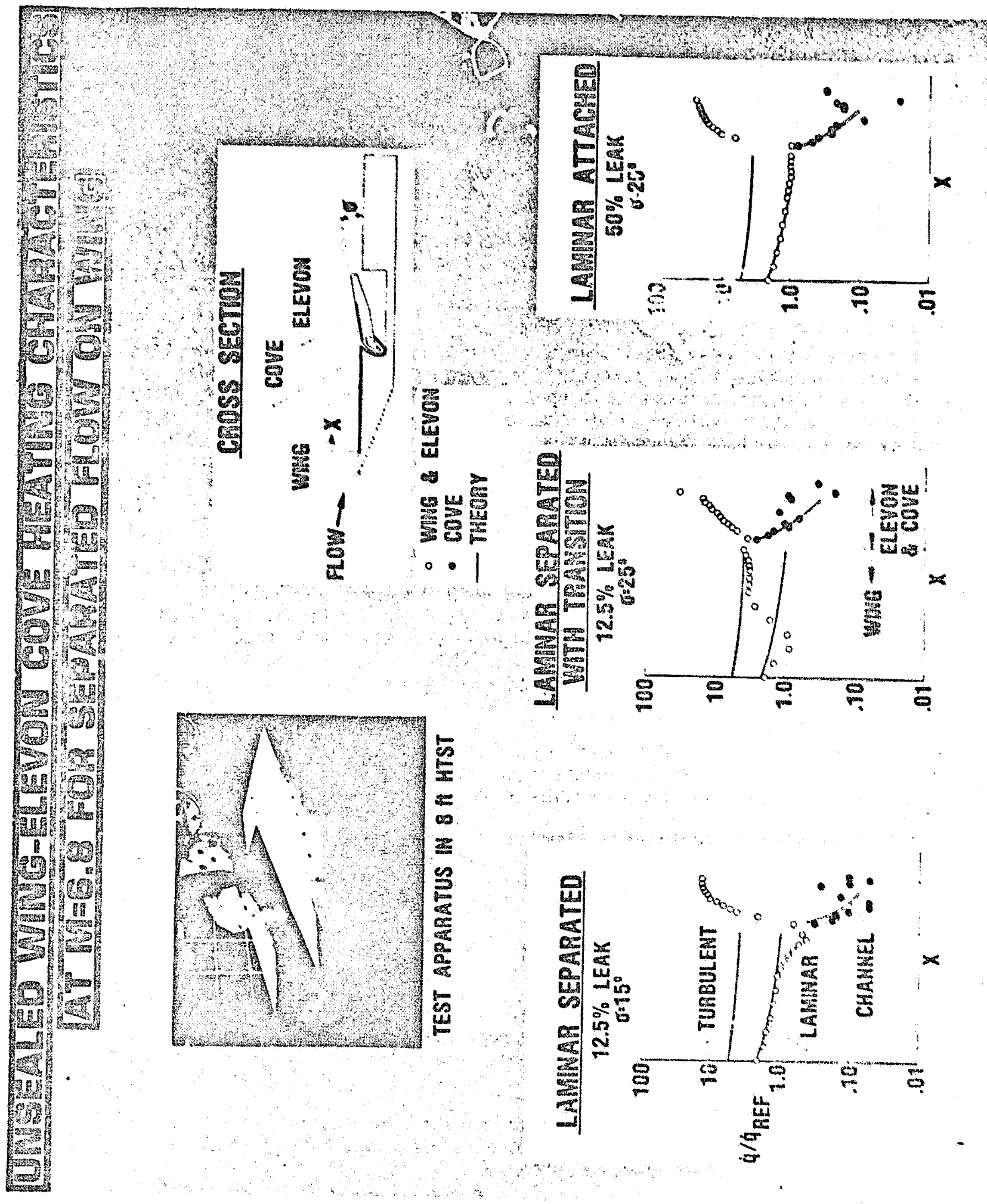

Figure 14(b).

NEW VIEW FACTOR CALCULATION TECHNIQUE MORE EFFICIENT

Claud M. Pittman
Aerothermal Loads Branch
Extension 3155

RTOP 506-53-53

Research Objectives

The objective is to develop an efficient view factor computer program suitable for calculating radiation view factors for large, complex structures.

Approach

A research grant was established with the University of Washington to develop an efficient view factor computer program for radiant heat transfer analysis. The view factor program development was also to include an interactive graphics program which would create and manipulate geometric shapes and provide the surface coordinate data necessary for view factor calculations. Recently, the programs have become operational.

Accomplishment Description

In-orbit thermal analysis of the LDEF payload, to be carried in the Space Shuttle (see figure), requires calculation of radiant heat transfer inside the LDEF configuration. To do the radiant heat transfer analysis, radiation view factors must be calculated for more than 400 internal surfaces of the payload. The view factor calculations for LDEF are complicated by the internal reinforcing structural members which produce more than 100 internal surfaces which partially block radiation between the outer surfaces. More than 60,000 view factors must be calculated.

Previously, view factors were calculated using a non-optimized, in-house computer program. This computer program required about 30 hours on the CDC-6600 computer to calculate view factors for a typical LDEF configuration.

The University of Washington view factor program has been used to calculate view factors for a typical LDEF configuration. The calculation required about 30 minutes on the Cyber-203 computer. Since the Cyber-203 computer is about twice as fast as the CDC-6600, the new program decreased computer time by a factor of about 30.

Future Plans

The capability to include solar radiation and umbra-penumbra effects will be incorporated into the view factor program. These additions will make the program suitable for calculating view factors for large space structure thermal analysis.

The new view factor program will be put in the COSMIC system and will be incorporated into the SPAR thermal computer program. The program will also be compared to the TRASYS computer program.

Figure 15(a).

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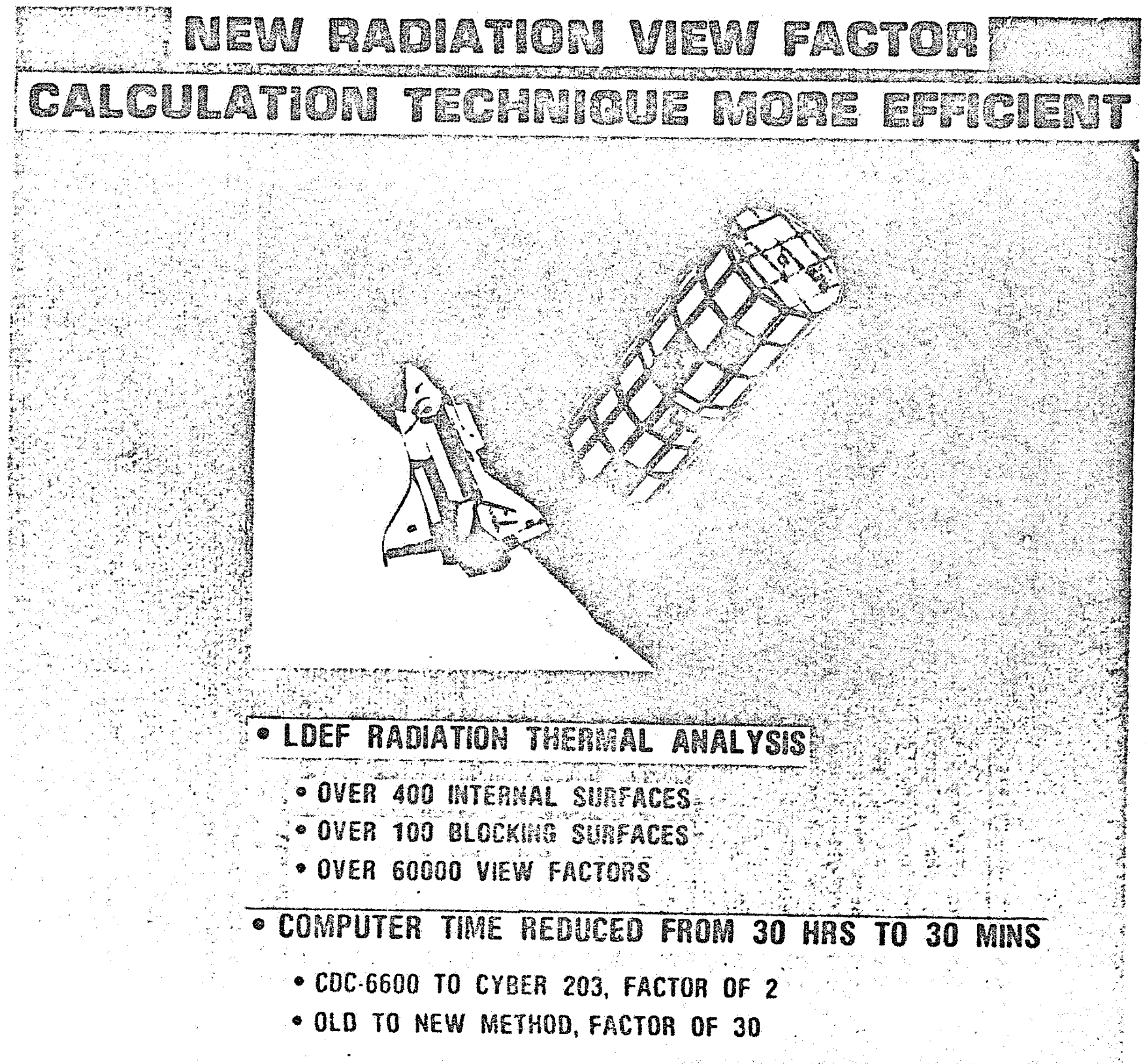


Figure 15(b).

ANALYSIS OF PRESSURE AND HEATING RATE DISTRIBUTIONS ON A THERMALLY BOWED TPS PANEL

George C. Olsen
Aerothermal Loads Branch
Extension 3168

RTOP 506-53-53

Research Objectives

Metallic TPS panels bowed by thermal gradients induced by aerothermal heating disrupt the original moldline of a hypersonic vehicle. In the past bowed-surface/flow-field interactions have been inferred from the results of 2-D flow over a wavy wall. This approach ignores the third dimension and suppresses many significant flow phenomena such as crossflow, 3-D relief, and vorticity formation. In an effort to accurately determine all flow phenomena, ALB has developed a more rigorous analytical model and a parallel experimental program.

Approach

Flow over a dome simulating a thermally bowed TPS panel has been modeled using a two-boundary mapping technique to generate a numerical grid and a vectorized MacCormack method algorithm to solve the 3-D Navier-Stokes equations. One-half of the dome region was modeled with symmetry planes occurring on the dome centerline and between adjacent domes. Results from a 2-D boundary layer analysis of flow ahead of the computational region provided the upstream input data. Other boundary values were determined by quadratic extrapolation from interior points.

Accomplishment Description

Results for Mach 7 flow over domed surfaces 1/2, 1, and 2 boundary layer thicknesses high have shown that maximum wall heating rates and pressures increase in an exponential fashion. Between values of zero and one heating rates increase by a factor of 2.3 and pressures by a factor of 2. Between values of zero and two they increase by factors of 6.2 and 5.6, respectively. However, due to corresponding lee-side reductions integrated loads over the panel do not increase for domed surfaces less than one boundary layer high. Domes two boundary layers high experience 25 percent increases in loads. Downstream wakes and vortices indicate following domes will experience much different conditions than leading domes.

Future Plans

Additional studies will be conducted to determine if dome diameter is a significant parameter. The effects on downstream domes, both aligned and staggered, will be investigated. The experimental program will collect data on small scale models to be tested in the ALB 7-Inch High Temperature Tunnel and on large scale models to be tested in the ALB 8-Ft. High Temperature Tunnel. These tests are scheduled for FY 84.

Figure 16(a).

PRESSURE AND HEATING RATE DISTRIBUTIONS ON A THERMALLY BOWED TPS

INITIAL RESULTS FROM A 3-D NAVIER-STOKES
ANALYSIS OF MACH 6 FLOW OVER A DOME
36,000 GRID POINTS — 180,000 DOF

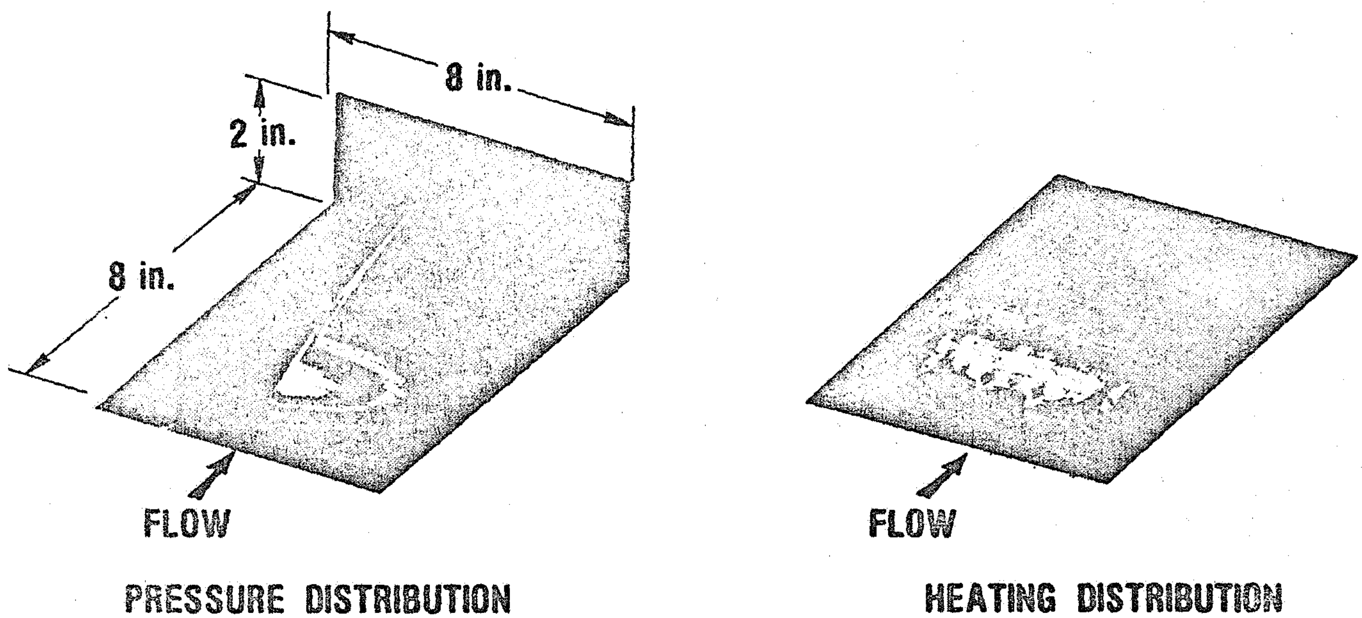


Figure 16(b).

8' HTT CERAMIC NOZZLE EVALUATION

Carl R. Pearson
John R. Karns
Aerothermal Loads Branch
Extensions 3423 and 2154

1980 CofF

Research Objective

The operation of the 8' HTT is restricted by the maximum allowable surface temperature of the metallic nozzle. Longer run times, bigger usable test core, and longer life could be realized if the present Inconel X nozzle could be replaced with one of an improved material. The important characteristics for a material are operation at 2000°F surface temperature, bulk strength, surface strength to resist erosion, capable of tolerating large thermal shocks, long economic life.

Approach

Nozzles using two different ceramic materials have been constructed and tested in the facility.

Accomplishment Description

Both materials withstood thermal shock and operation at high temperatures but, due to surface roughness, did not permit decreased boundary flow which would have enlarged the usable test core. The Resco material had better erosion properties but lacked the bulk strength for high pressure runs. The silica material, as fabricated, had sufficient bulk strength but insufficient surface strength to meet erosion.

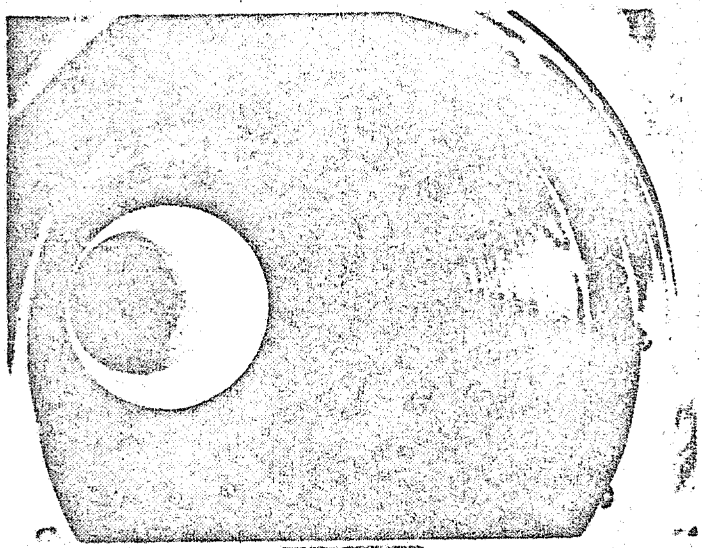
The CofF project is being closed out by constructing a nozzle of Nickel 200 which, because of its high ductility, should increase nozzle life by a factor of 500. This will accomplish one of the three original goals.

Future Plans

Although a fertile field for additional research, no additional work with ceramic nozzles is planned in the near term because of funding limitations.

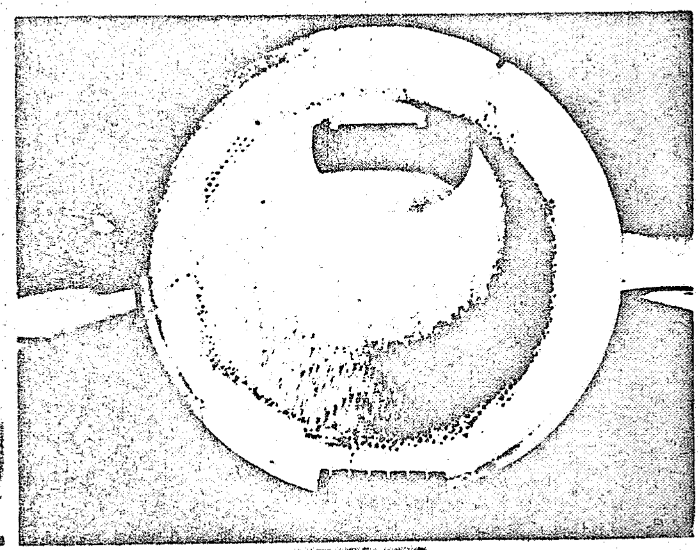
Figure 17(a).

8-FT HTST CERAMIC NOZZLE EVALUATION



RESCO

- EROSION RESISTANT
- FAILED AT 2000 psi



SILICA

- STRENGTH DEMONSTRATED
- ERODED/POOR PROCESSING

- MATERIALS/COATING RESEARCH REQUIRED
- 80 CoF MODIFIED TO N200 SECTION WITH ESTIMATED LIFE 500 TIMES CURRENT INCONEL X

Figure 17(b).

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SECOND MINIMUM NOZZLE INSERT YIELDS UNIFORM MACH NUMBER REDUCTION

Richard L. Puster
Aerothermal Loads Branch
Extension 3115

RTOP 506-53-63

Research Objective

Currently, the 8' HTT provides flight simulation conditions from Mach 6 to 7 at altitudes of 80 to 130 kft. With its large test section, the 8' HTT can easily test full scale airframe integrated scramjet engines, missiles, and other full scale components. However, these engines and missiles operate over a large Mach number range beginning at approximately 4. Tests are currently underway in the 1/12th scale 7" HTT of the 8' HTT to investigate ways of altering the test section Mach number. The test program supports part of the FY 85 CofF proposal to expand the test capability of the 8' HTT.

Approach

A simple second minimum insert was placed in the expansion region downstream of the first throat. Wide ranges of Mach number decrease were easily achieved. The insert has boundary layer flow bleeds to stabilize the compression shock wave and to alleviate the strength of the turning shock wave system at the exit of the insert. The compression surface of the insert generates very strong shock waves and central Mach discs; the reexpansion after the second supersonic throat helps to attenuate this shock wave--Mach disc system. In addition, the exit pressure of the boundary bleed is much higher than nozzle static pressure and thus creates a large region of separated flow (solid area downstream of insert) that gradually turns the expanding exit flow from the insert.

Accomplishment Description

Various inserts have been tested with rather interesting results. With normal operational flow parameters, the resulting flow is very non uniform with variations in Mach number and total pressure of about 20 percent with the lower values occurring near the flow centerline. However, when large quantities of coolant air are used (1/3 or more of total nozzle flow) the resultant flow in the test section is fairly uniform with a Mach number of 4.6. The Mach discs and shock waves cannot be photographed or detected, and thus must have been attenuated to a great extent by the expanding flow. Surprisingly, large models can be inserted with no flow unstart. The small insert could be relatively inexpensive, expand the Mach number capability of the 8' HTT, and not require extensive modifications to the facility.

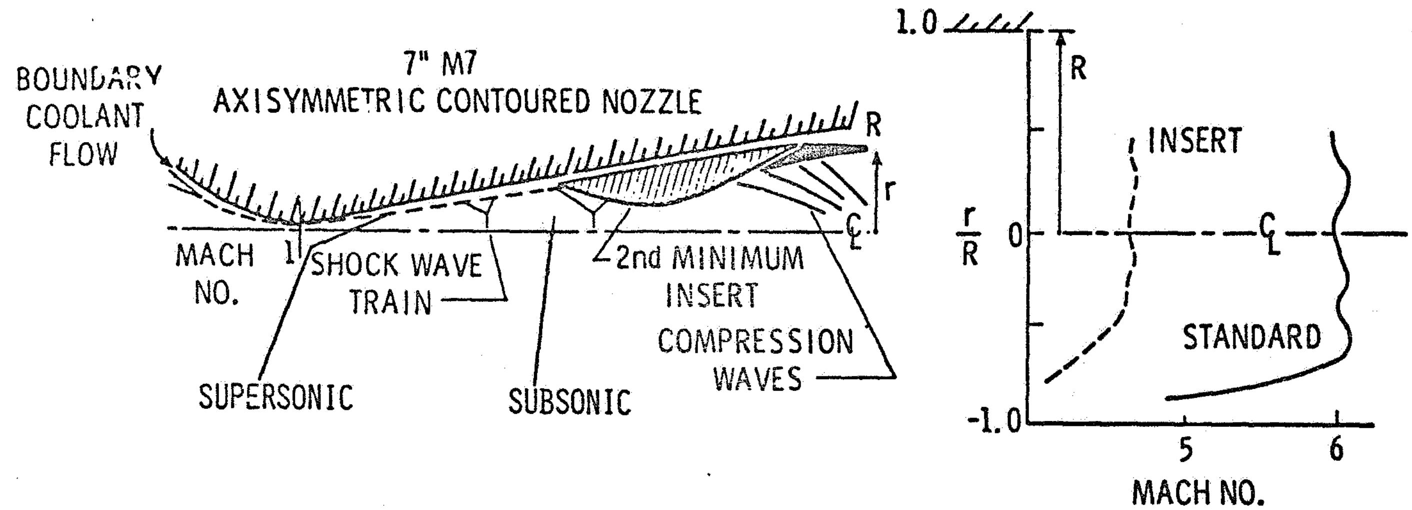
Future Plans

It appears that an insert design with good peripheral flow removal at the insert inlet and strong flow injection at the trailing end may be very promising for Mach number reduction. However, the complex flow mechanisms are not completely understood at this time. Tests, development, and analysis are continuing.

Figure 18(a).

SECOND MINIMUM NOZZLE INSERT YIELDS UNIFORM MACH NUMBER REDUCTION

M = 6 TO M = 4.6



- OTHER MACH NUMBERS OBTAINABLE
- INVESTIGATION CONTINUING TO OBTAIN DESIGN DETAILS OF SELECTED DUAL THROAT - MIXER CONCEPT

Figure 18(b).

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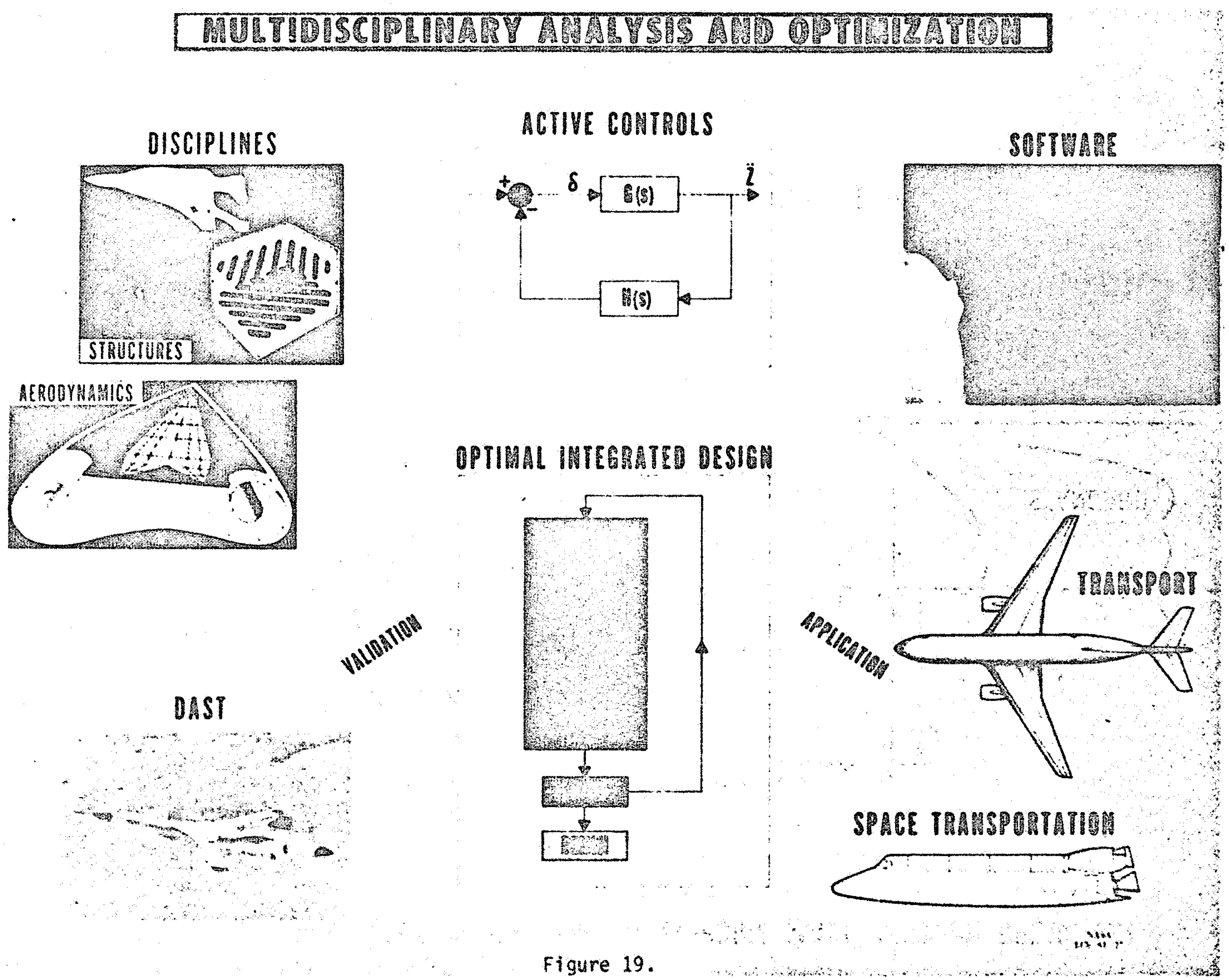

Figure 19.

MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATIION
5 YEAR PLAN

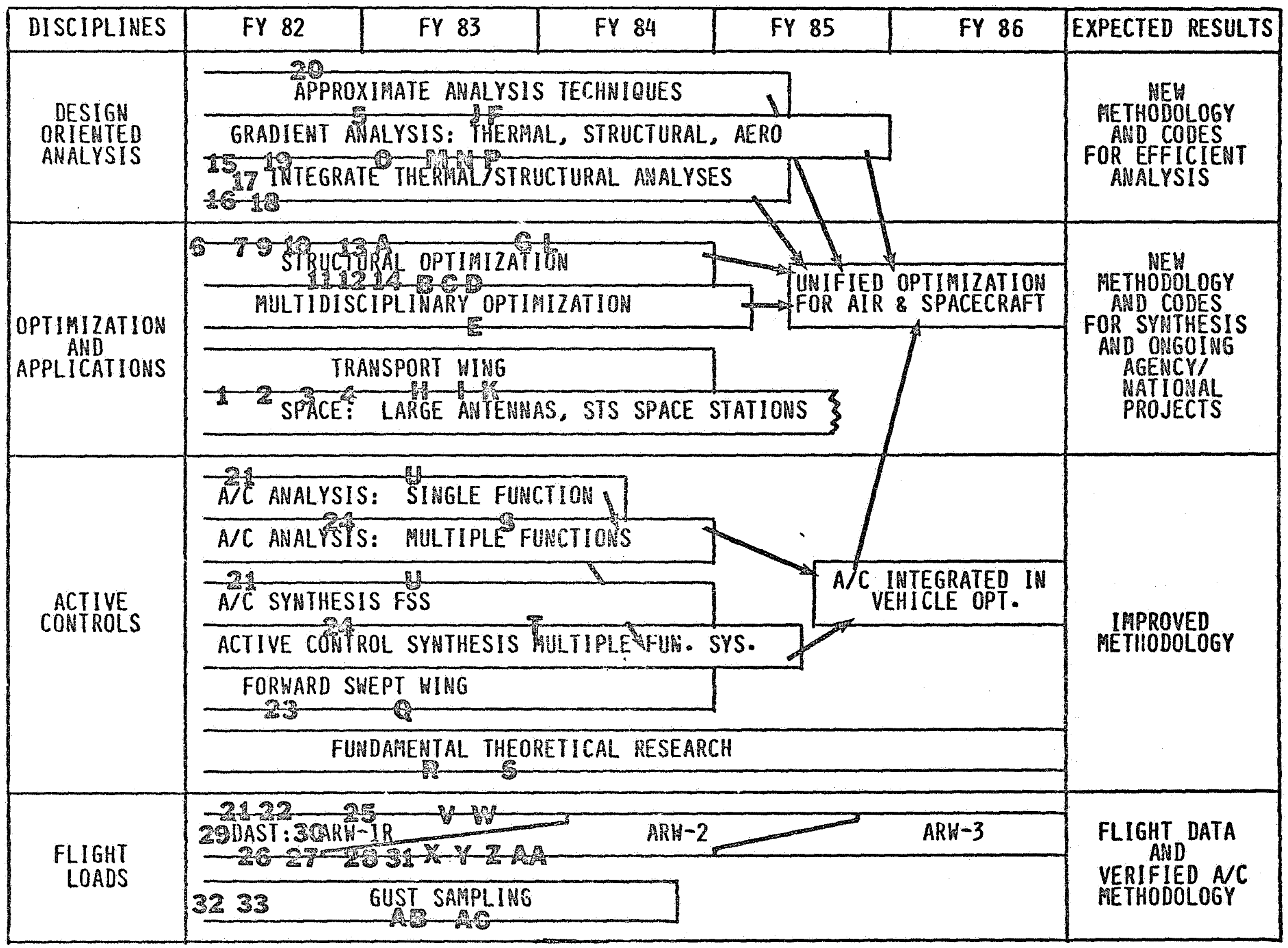

Figure 20.

MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION

FY'82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP MILESTONES/ACCOMPLISHMENTS	SIGNIFICANCE	STATUS
	506-53-53		
1	Develop aerodynamic paneling for Space Shuttle Orbiter with wingtip fin (1/82).	Structural design had to be created first.	Rescheduled.
2	Develop finite-element model for above (4/82).	Acceptable structural design, previously nonexistent, has been created.	Design and FEM developed, static analysis checked out.
3	Develop thermal model for above (7/82).	Structural design had to be created first	Rescheduled (see I FY'83)
4	Integrate in ISSYS computer programs pertinent to orbiter needs (9/82)	Creating analysis for new design.	Static & flutter complete.
5	Develop gradient analysis for static displacements, temperatures, forces, and stress in EAL (9/82)	General gradient capability available in widely used high-level language, production program.	Complete.
	505-33-63		
6	PROSSS in EAL completed (10/81).	General purpose structural optimization available in a widely used, high-level language, production program.	Complete.
7	A method for aeroelastic tailoring of low-aspect-ratio very flexible wings completed (2/82)	A significant step toward a unified optimization of aircraft.	Complete for metal wings, composite wings work terminated due to lack of in-house support of SST.

Figure 21(a).

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FY'82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP MILESTONES/ACCOMPLISHMENTS	SIGNIFICANCE	STATUS
	505-33-63		
8	Dynamic and static analysis of ARW-2 (4/82).	Flight test program support.	Postponed due to priority given to fix of ARW-1. (see T, FY'83)
9	Distributed optimization system on PRIME and NOS documented (3/82).	First demonstration of two dissimilar computers working in one iteration loop.	Completed.
10	Primal-dual optimization method adopted for dynamics (5/82).	There is no effective solution now for structural dynamic optimization on a large scale. This may offer a solution.	A variant of the method based on combinatorial mathematics being tested. (see L, FY'83)
11	General purpose modular optimizer prototype (6/82).	The first modular and open-ended optimization program to be available for a wide variety of programs.	A core program functional. (see D, FY'83)
12	Multilevel optimization method tested in structural optimization (6/82).	First demonstration of the proposed decomposition of a large optimization problem into a set of smaller subproblems.	Completed, a paper proposed for SDM CY'83.
13	First phase of the fuel efficient wing optimization task completed (9/82).	First industrial scale demonstration of a concept for unified optimization of aircraft as an engineering system.	Delayed 6 months due to changing the aircraft design. (see C, FY'83)
	505-36-13		
14	Structural shape optimization method (9/82).	There is no effective solution now for structural shape optimization on a large scale. This method might be a solution.	Grant on schedule. (see F, FY'83)

Figure 21(b).

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FY'82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP MILESTONES/ACCOMPLISHMENTS	SIGNIFICANCE	STATUS
	506-53-53		
15	Initiate contract to implement SPAR improvements (11/81).	SPAR thermal analyzer becoming key analytical tool for STS and spacecraft.	Contract underway. SPAR improvements documented in conference paper 11/3/81.
16	Initiate grant with VPI&SU (Haftka) for thermal structural optimization (11/81).	Will provide improved capability for optimization of reentry vehicles and spacecraft.	Grant initiated 10/15/81. Improved methods documented in conference paper and NASA TP.
17	Conduct conference on structural heat transfer at LaRC.	Provides timely interchange of latest advances.	Conference held Nov. 3-5, 1981. NASA CP-2216, April 1982.
18	Demonstrate benefits of simultaneous optimization of structure and TPS (1/82)	Potential mass savings relative to sequential design.	Procedure developed and documented in conference paper August, 1982.
19	Complete pilot vectorized thermal analyzer on CYBER 203 (3/82).	Test bed for assessing reduction in solution time using vector computation.	Work complete and documented November, 1981.
20	Complete development of reduced-basis technique for transient thermal analysis (5/82).	Useful analysis technique for dynamics. Has potential payoff for thermal analysis.	Procedure developed and checked out. Two conference papers prepared.
	505-33-63		
21	Synthesis and analysis of a new flutter suppression system for DAST ARW-1 (1/82).	In house design using optimal methods of FSS to be flight tested on DAST ARW-1R.	Complete (system to be updated during flight tests).
22	Analysis of DAST ARW-2 active control laws (2/82).	Support of DAST program. Evaluate contractor design.	To be completed Sept. 1982.
23	Investigation of active control application to FSW (4/82).	Control of aeroelastic instability of FSW.	Definition of body freedom using bending instability. (see Q, FY'83)

Figure 21(c).

FY'82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP MILESTONES/ACCOMPLISHMENTS	SIGNIFICANCE	STATUS
24	Low-order synthesis methodology for multifunctional active control systems (8/82)	Application of matrix singular values in the design of multiloop systems.	Evaluation of gain and phase margins for multiloop systems using matrix singular values.
25	Optimization of control laws for DAST ARW-2 (9/82).	Development of control law synthesis methodology for *multiple active control systems.*	Delayed due to ARW-1 design. (see T, FY'83)
	505-33-53		
26	Complete all-up GVT of ARW-1R (12/81).	Verification of structural model.	Results incorporated in flutter analyses.
27	Validate FSS operation to above system-off boundary (4/82).	Initial flight evaluation of new FSS.	DAST ARW-1R ready for first flight.
28	Complete FSS assessment flights (ARW-1R) (9/82).	Data available for detailed evaluation of FSS design methodology.	Now expected to complete first quarter CY'83. (see V, FY'83)
29	ARW-2 structural assembly complete (11/81).	Wing available for auxiliary equipment installation.	Auxiliary equipment installation underway.
30	Active control system delivery (4/82).	System ready for installation and familiarization.	Delivery pending decision on integration test.
31	ARW-2 instrumentation complete (9/82).	Wing ready for wind tunnel test.	Center section installation complete. (see Y, FY'83)
32	Complete instrumentation system installation including tip booms on B-57B (9/81).	Instrumented aircraft ready for sampling flights.	Aircraft in flight status.
33	Begin flight samplings (10/81).	Provide data on spanwise gradients of atmospheric turbulence.	Eleven flights conducted in Denver area as part of JAWS program.

Figure 21(d).

DAST ARW-1R FSS PERFORMANCE

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Multidisciplinary Analysis and Optimization Branch
Extension 3169

RTOP 505-33-53

Research Objective

In preparation for renewed flight testing of DAST (Drones for Aerodynamic and Structural Testing) ARW-1 (the first research wing of the program, now designated ARW-1R), a new flutter suppression system has been designed at the LaRC. The system will provide an increase in flutter speed of 10 percent over that of the passive wing. The objective of this research is to validate the analysis and synthesis methods used to design active control systems.

Approach

The flutter suppression system to be flight tested on DAST ARW-1R was designed using synthesis methods developed at LaRC. Optimal control techniques were used to design the present system. The design objective of increasing the flutter speed by 10 percent while maintaining satisfactory gain and phase margins has been achieved. The control law performance margins are attained by gain scheduling as a function of dynamic pressure.

Accomplishment Description

Analytical results showing the performance of the symmetric flutter suppression system at an altitude of 13,000 feet is presented in the accompanying figure. At this altitude, the predicted passive flutter speed is approximately $M = 0.85$. With the flutter suppression system turned on, a significant increase in flutter mode damping and a decrease in flutter frequency is indicated. At this altitude, the aircraft is flutter free to speeds above the 10 percent requirement.

Future Plans

The flutter suppression system has been implemented aboard the DAST ARW-1R flight vehicle. All ground checkouts of the system have been successfully completed. Flight flutter testing is to resume in the first quarter of CY 1983. Flight measurements of system performance will be compared with analytical results in order to validate synthesis and analysis methods. It is anticipated that the 10 percent increase in flutter speed will be demonstrated during the second quarter of CY 1983.

Figure 22(a).

DAST ARW-IR FSS PERFORMANCE

ALT = 13000 FT, SYMMETRIC FLUTTER MODE

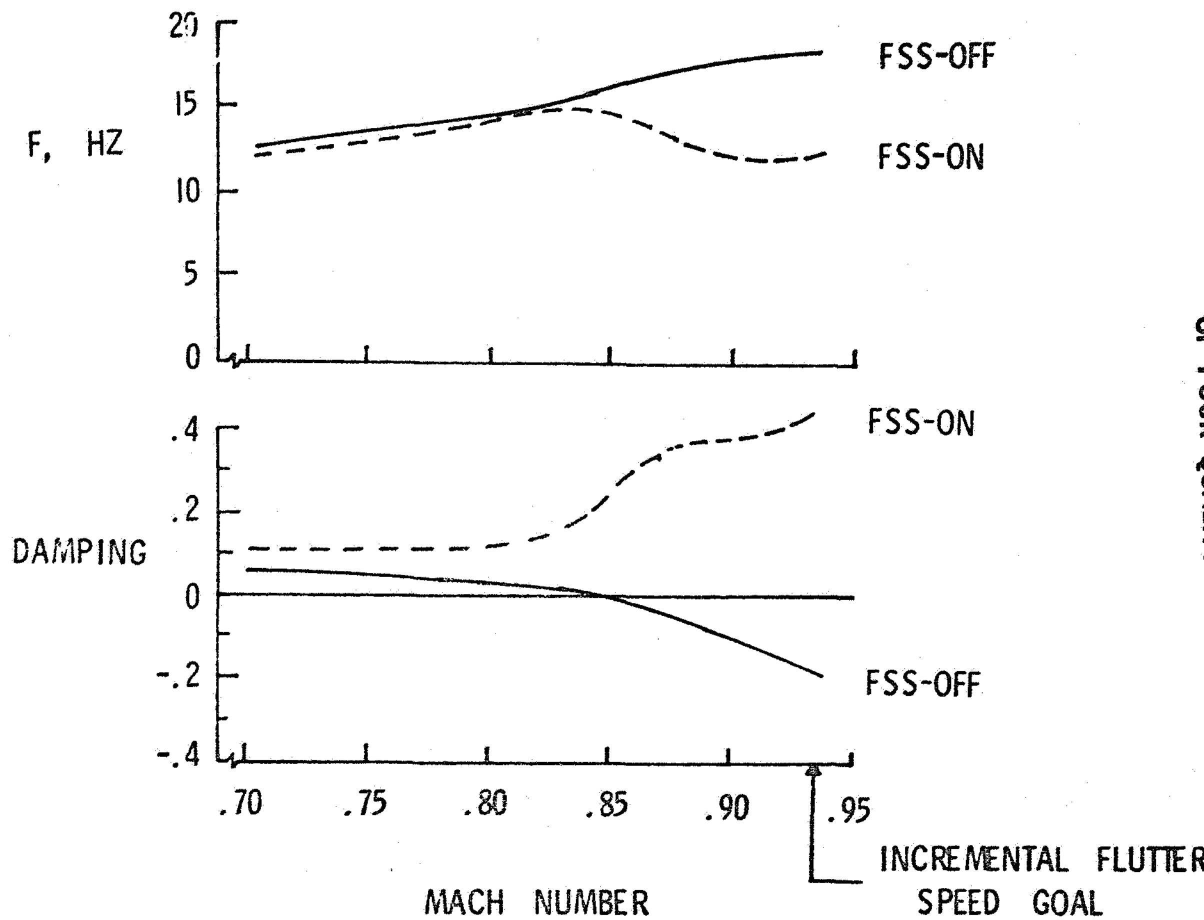

Figure 22(b).

IMPLEMENTATION OF STATIC AND DYNAMIC STRUCTURAL SENSITIVITY CALCULATIONS

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RTOP 506-53-53

Research Objective

The objective of this research is to develop the capability to calculate sensitivity derivatives of displacements, stresses, vibration modes and frequencies, and buckling modes and loads with respect to design parameters for finite-element-modeled structures.

Approach

Methods for calculating structural sensitivities: (1) finite difference, (2) analytical, and (3) semianalytical were implemented in Engineering Analysis Language (EAL) finite-element analysis program. Runstreams were developed to calculate structural sensitivities with respect to structural design parameters such as area, thickness, moment of inertia, etc. An analytical method for calculating dynamic structural sensitivities denoted Nelson's Method was also implemented.

Accomplishment Description

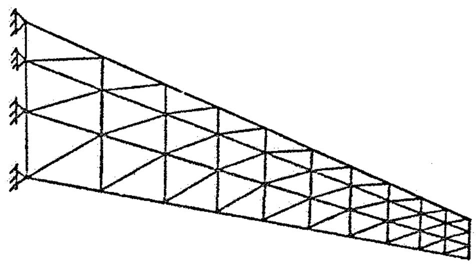
Comparisons of CPU time, degree of programing difficulty, accuracy, and generality were made for three sample problems: a swept wing, a box beam, and a stiffened cylinder with a cutout (see figure). The swept wing results for $\partial u/\partial v$ indicate that the semianalytical method can reduce the CPU time of the finite-difference method by 40 percent. Using the LSK Processor, which enables the selection of appropriate submatrices of the K matrix, the CPU time can be reduced by 77 percent, making it competitive with the analytical method. Linear design variable linking was used in the box beam problem and results from finite difference and a combination of analytical and semianalytical methods is shown. In the combined method, the calculation of derivatives was done analytically for all membrane elements and was done semianalytically for all bending elements. The savings in CPU time are not as dramatic as the swept wing problem because of the logic involved in the linking and the smaller size (nine design variables) of the box beam problem. Derivatives of displacements, stresses, and vibration modes and frequencies were calculated for a stiffened cylinder with a cutout as shown in the figure. Prasad's method was used to calculate stress derivatives and Nelson's method was used to calculate dynamic sensitivities. Nelson's method reduces CPU time by 55 percent over the finite-difference method.

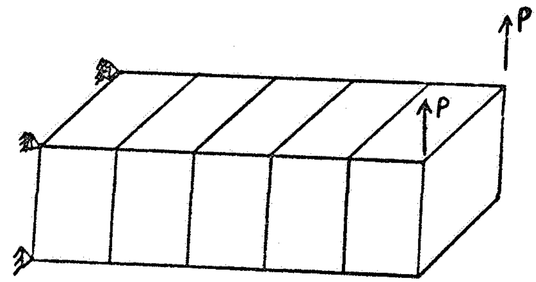
Future Plans

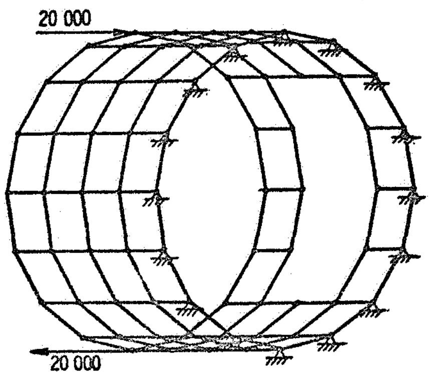
The accomplishments to date are being documented in a proposed NASA TP. Incorporation of a generalized design variable linking algorithm is presently underway. The addition of shape and material design variable derivatives is also planned for future incorporation.

Figure 23(a).

STRUCTURAL SENSITIVITY CALCULATIONS IMPLEMENTED IN EAL







SWEPT WING

- o 160 D.O.F.
- o 194 ELEMENTS
- o 32 DESIGN VARIABLES
- o 2 LOAD CASES

BOX BEAM

- o 122 D.O.F.
- o 75 ELEMENTS
- o 9 DESIGN VARIABLES
- o 1 LOAD CASE

STIFFENED CYLINDER

- o 337 D.O.F.
- o 190 ELEMENTS
- o 3 DESIGN VARIABLES
- o 1 LOAD CASE
- o 2 VIBRATION MODES

SOLUTION TIMES IN CPU SEC

	$\partial u/\partial v$
FINITE DIFFERENCE	700
SEMI-ANALYTICAL	161

	$\partial u/\partial v$
FINITE DIFFERENCE	141
SEMI-ANALYTICAL	61

	$\partial u/\partial v$	$\partial \sigma/\partial v$	$\partial \omega/\partial v$, $\partial \phi/\partial v$
FINITE DIFFERENCE	222	230	423
SEMI-ANALYTICAL	175	186	190

Figure 23(b).

DAST ARW-1R GROUND VIBRATION TEST

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Extension 2012

RTOP 505-33-43

Research Objective

The major objectives of DAST are to compare experimental results with prediction. For the first aeroelastic research wing, ARW-1, accuracy of the flutter predictions are dependent on a valid structural model. The objective of the all-up ground vibration test (GVT) with the instrumented research wing mated to the flight vehicle is to provide the final information relating to wing structural characteristics prior to flight.

Approach

The development of the analytical structural model is an iterative process, with updating whenever additional experimental data are available. The GVT was performed using a shaker driven by a random noise signal where all frequencies are excited simultaneously in lieu of sinusoidal excitation through a range of frequencies. The all-up DAST ARW-1R (rebuilt) GVT was performed in April 1982. Results from this test in the form of frequencies and mode shapes provided data for final updating of the analytical structural model and final flutter analyses subsequently performed. Before the first flight test and between flight tests, the frequencies of the wing are checked with wing excitation via the calibrated hammer technique.

Accomplishment Description

The accompanying photograph was taken during the test series. The table in the lower right portion of the figure gives frequency values predicted prior to the test in the second column from the left and the measured frequencies in the third column from the left. As a results of this test, the analytical structural model was adjusted and the resulting frequencies are given in the column at the right. The adjustment was made in the glove region where the wing is attached to the fuselage.

Future Plans

In the flight tests, wing loads will be measured via surface pressure measurements and calibrated strain gage bridges. The measured and predicted flutter boundaries will be compared as well as variation of the frequencies of the dominant modes with dynamic pressure. One of the ultimate objectives of the program is to evaluate the accuracy and adequacy of the derived analytical structural model.

Figure 24(a).

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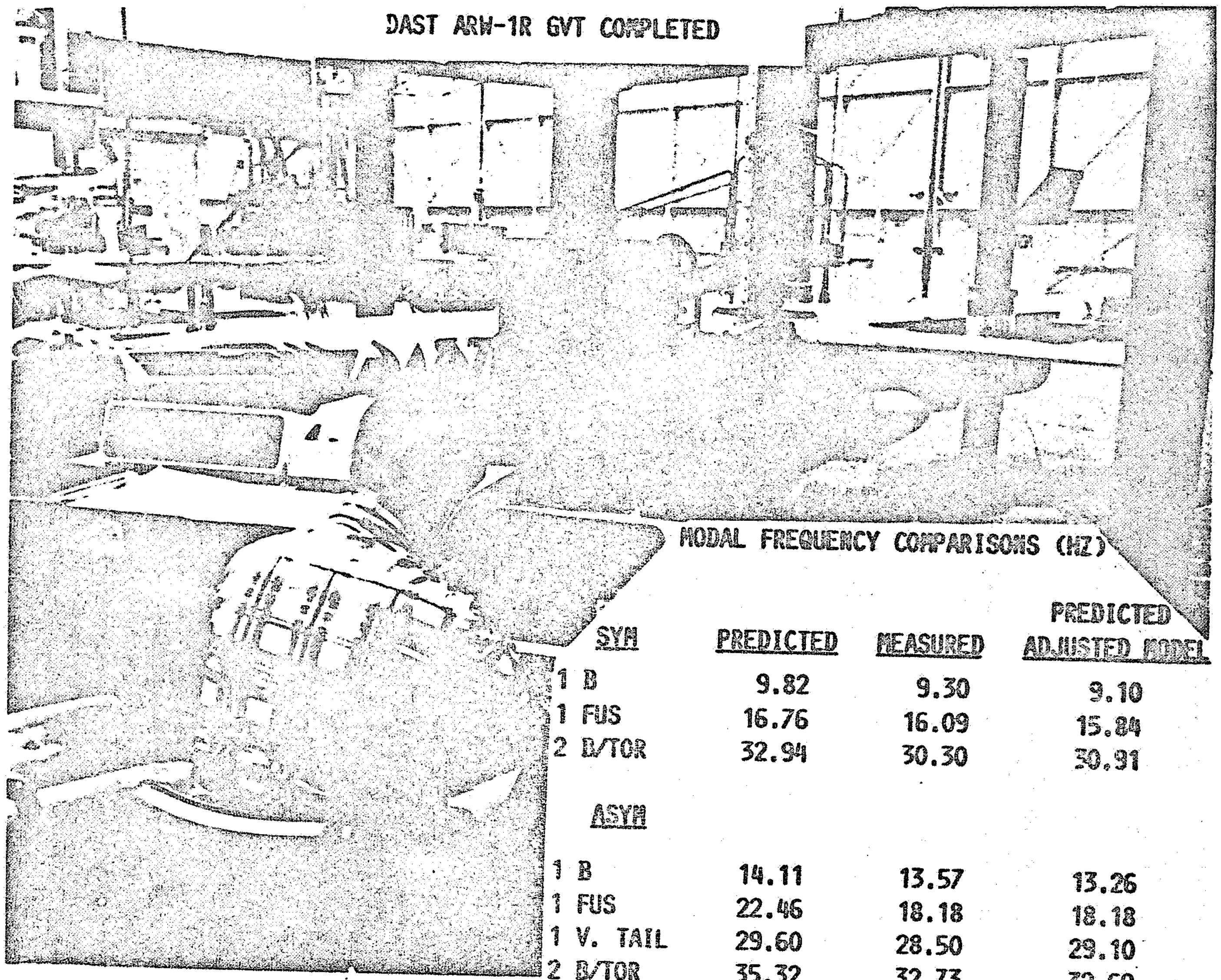
DAST ARW-1R GVT COMPLETED



MODAL FREQUENCY COMPARISONS (HZ)

SYM	PREDICTED	MEASURED	PREDICTED ADJUSTED MODEL
1 B	9.82	9.30	9.10
1 FUS	16.76	16.09	15.84
2 B/TOR	32.94	30.30	30.91
ASYM			
1 B	14.11	13.57	13.26
1 FUS	22.46	18.18	18.18
1 V. TAIL	29.60	28.50	29.10
2 B/TOR	35.32	32.73	32.69

Figure 24(b).

MULTILEVEL OPTIMIZATION

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RTOP 505-33-53

Research Objective

The objective is to develop an optimization methodology for an engineering system which is too large to be optimized as one optimization problem.

Approach

A large system is decomposed for optimization purposes into its component parts (subsystems) arranged into a pyramid-like hierarchy which may include several levels. Each subsystem at a given level represents several subordinated subsystems at the levels below. Interactions between the levels are formulated mathematically to preserve the physical couplings that occur in the assembled system. An optimum solution for each subsystem is then found independently and a coordination problem is solved to account for the interactions. The procedure is repeated iteratively until the optimum solutions at all levels converge. When the system being designed is an aircraft, the typical subsystems are: (1) aerodynamic shape envelope; (2) airframe; (3) propulsion, etc.

Accomplishment Description

A mathematical formulation for the entire procedure has been developed. To test its convergence and overall computational performance, it was adapted to structural optimization. In this application, the decomposition concept leads directly to analysis by substructuring. A framework structure (figure b) was selected as a test case and several numerical results were obtained. The results showed that the proposed method converged to the solution comparable with the reference results obtained without decomposition (figure c). No convergence problems were experienced. The positive test results may be interpreted as an indication that the method should also be effective in its general form which is applicable to engineering systems in which structure is only one of many subsystems.

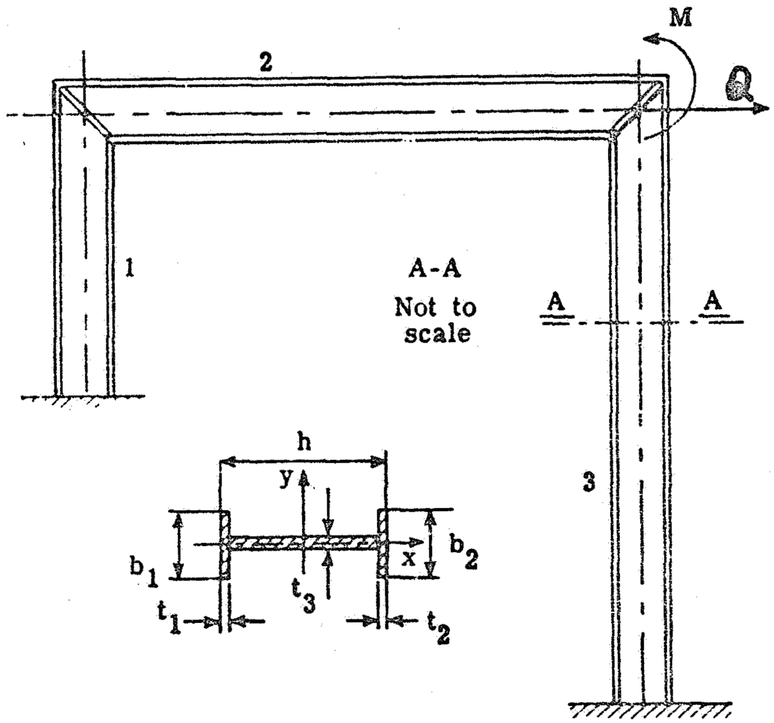
Future Plans

The procedure will be tested for structures other than frameworks, and subsequently will be evaluated for engineering systems such as aircraft. The approach will be tested on an example of a passenger transport aircraft of the L-1011 class (figure d) as a joint venture with the Lockheed-California Aircraft Co. and with participation of the Lockheed-Georgia Aircraft Co. The Langley group will carry out the optimization by means of the proposed method while the Lockheed-California group will use their state-of-the-art tools. The starting design will be common and the optimum designs will be compared to evaluate the proposed method against the state of the art. The FY 1983 plan calls for reconciliation of the analysis results and one pass through the structural optimization part of the entire task.

Figure 25(a).

EXAMPLE: A PORTAL FRAMEWORK

CONVENTIONAL APPROACH: ALL VARIABLES IN ONE VECTOR



OPTIMIZATION PROBLEM:

- $\min_{\vec{V}} F(\vec{V})$ STRUCTURAL MASS

  SUBJECT TO

  $G_J(\vec{V}) \leq 0;\ J \in J$

- $\vec{V} = \{H, B_1, T_1, B_2, T_2 \ldots\}$
- CONSTRAINTS G_J: FRAMEWORK DISPLACEMENT
  STRESS
  LOCAL BUCKLING

- DESIGN VARIABLES: TOTAL OF 6 x 3 = 18

Figure 25(b).

VERIFICATION OF MULTILEVEL OPTIMIZATION

TEST CASE: FRAMEWORK STRUCTURE

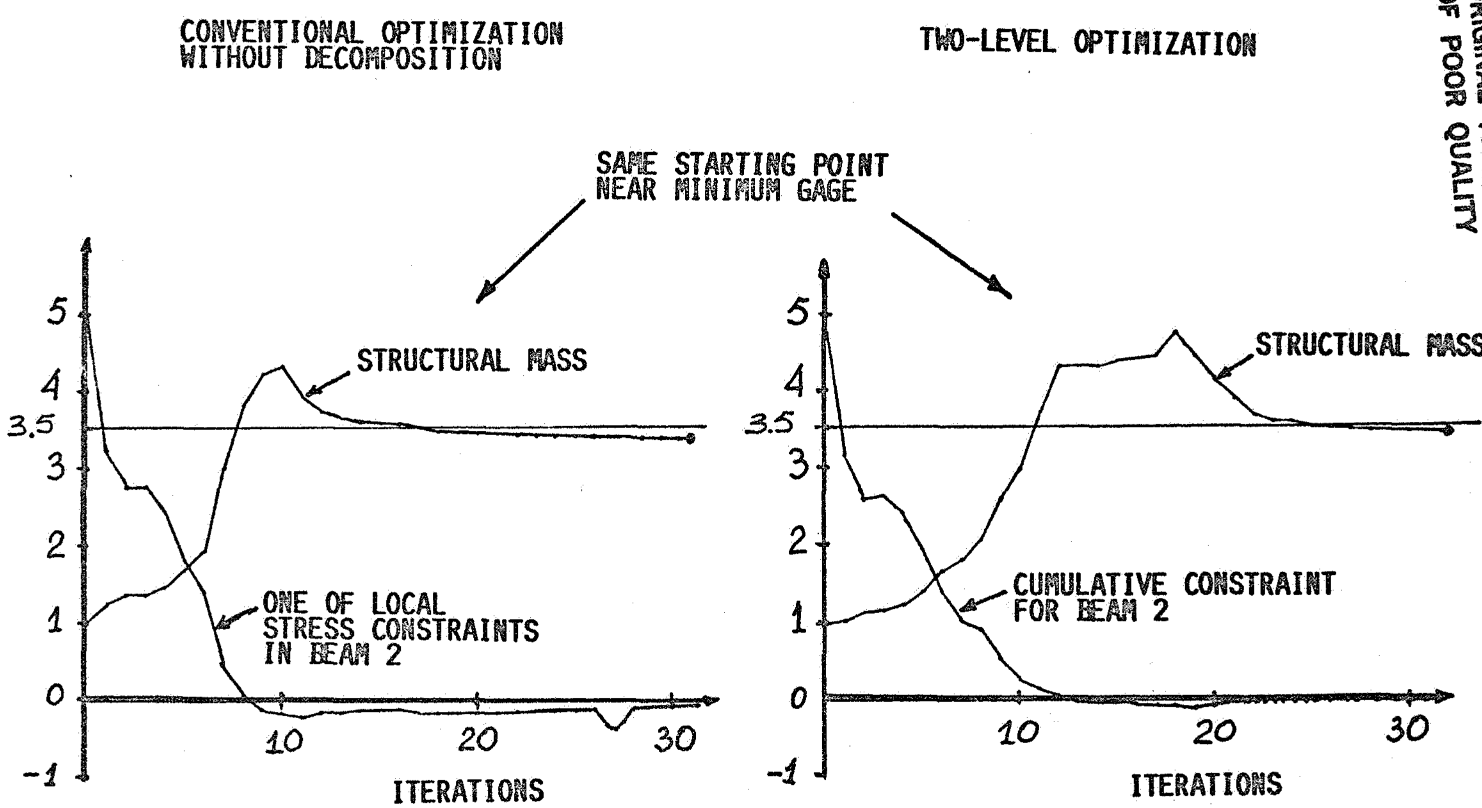


Figure 25(c).

A TEST CASE FOR MULTILEVEL OPTIMIZATION

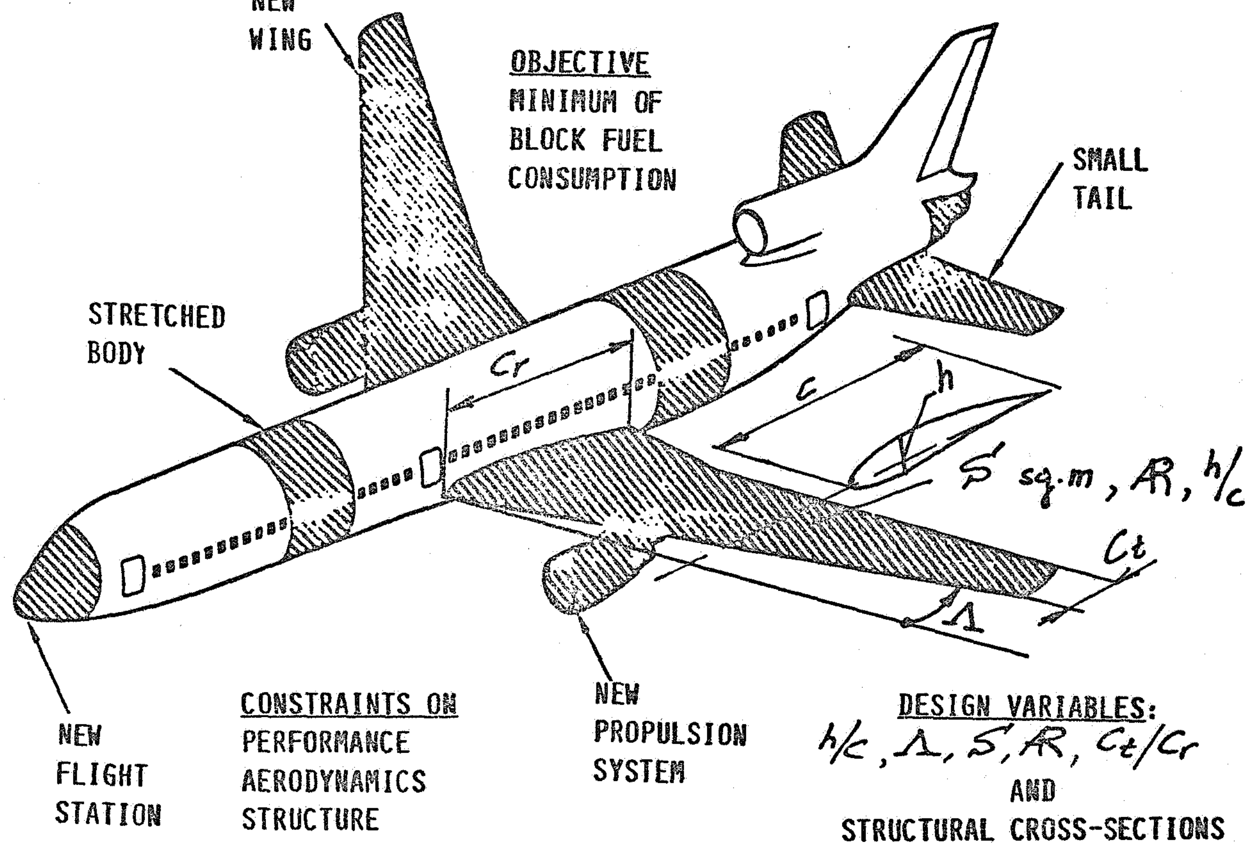


Figure 25(d).

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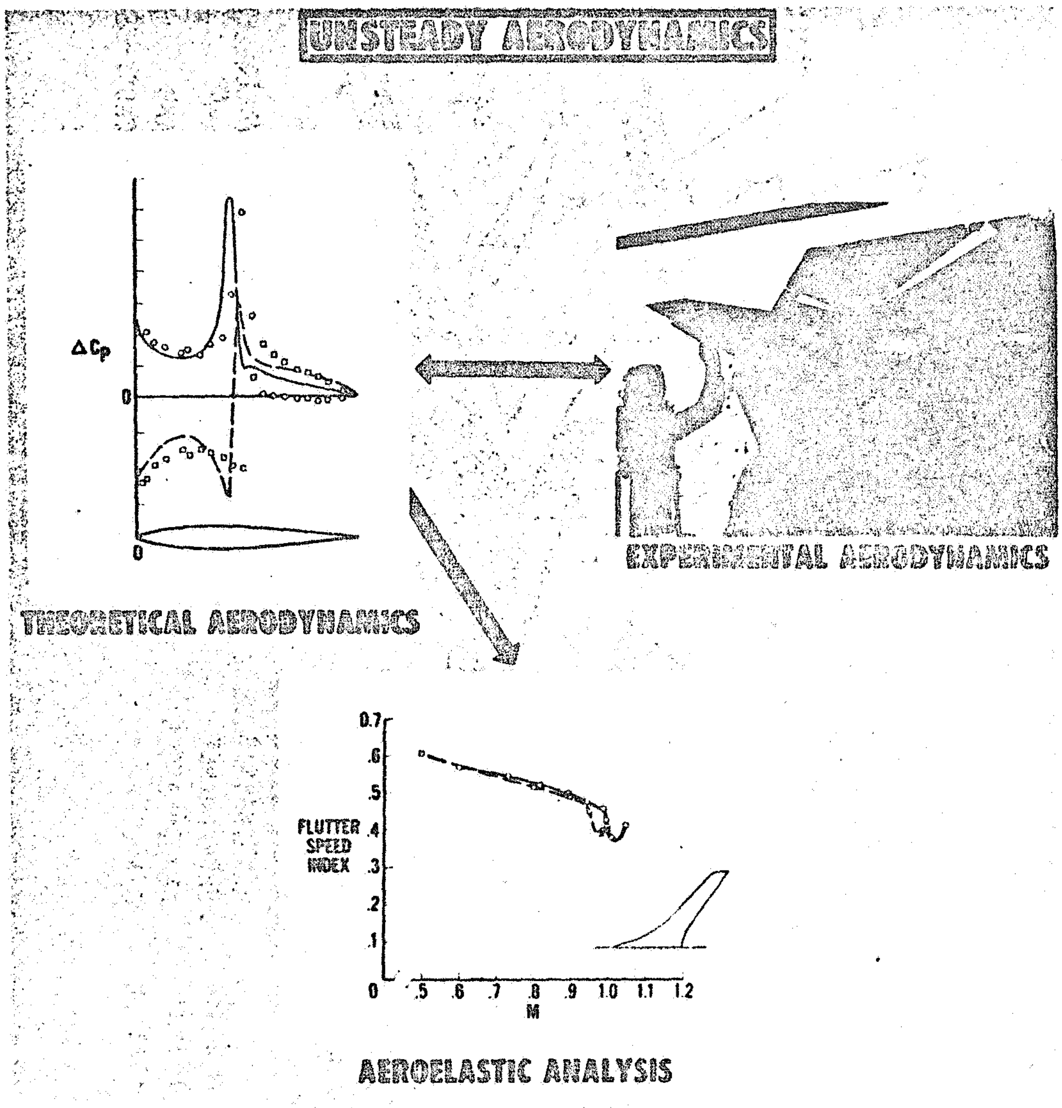

Figure 26.

UNSTEADY AERODYNAMICS
5 YEAR PLAN

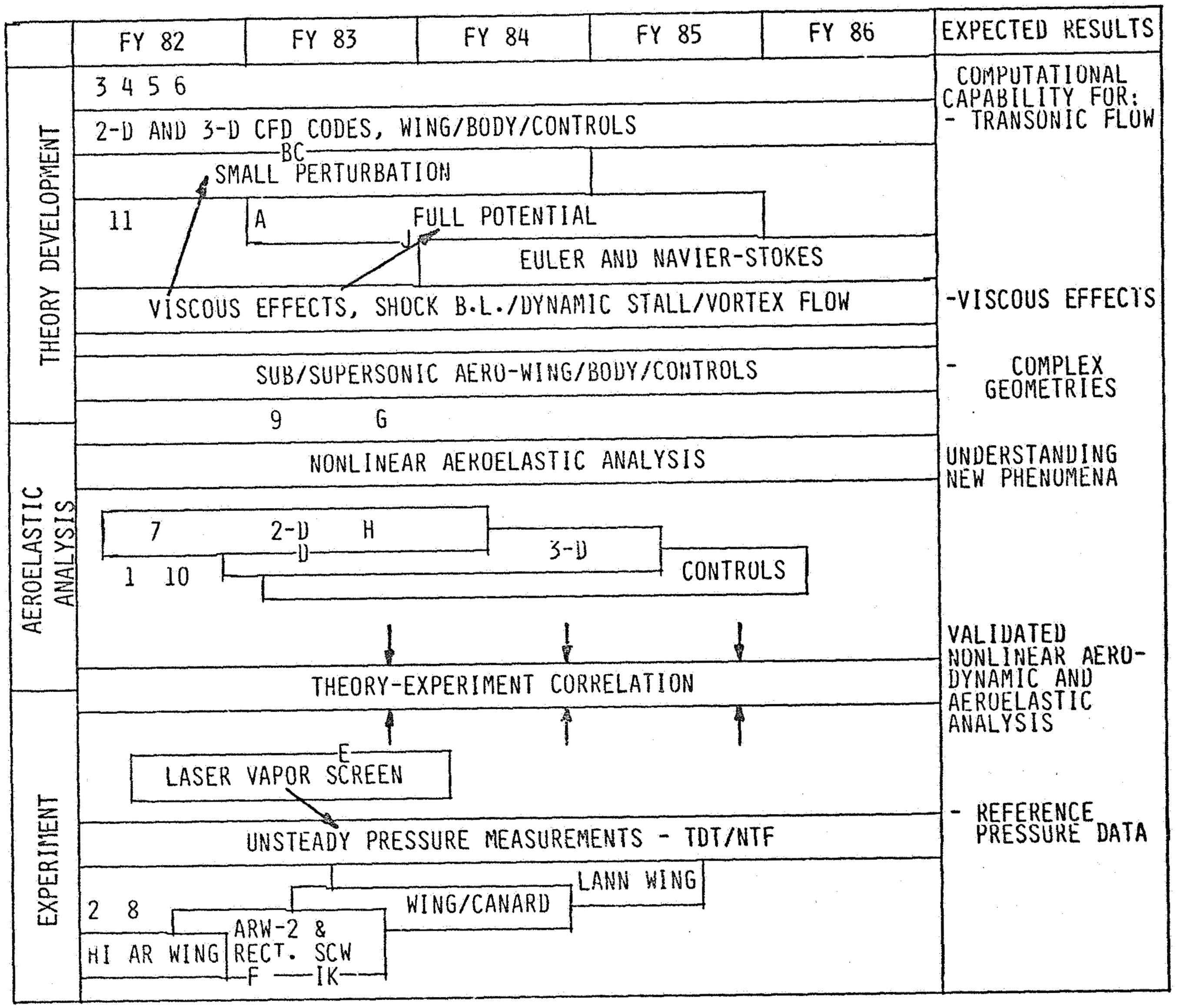

Figure 27.

UNSTEADY AERODYNAMICS
FY-82 MILESTONES/ACCOMPLISHMENTS

RTOP	MILESTONE	SIGNIFICANCE	STATUS
505-33-53	1. AEROELASTIC STUDIES INITIATED WITH XTRAN3S CODE, OCT. 1981	CALCULATION OF 3-D TRANSONIC UNSTEADY PRESSURES AND FLUTTER	GRID PROBLEMS UNDERSTOOD AND CALCULATIONS PROCEEDING
	2. REPORT RESULTS OF 6/80 UNSTEADY PRESSURE MEASUREMENTS ON ACEE WING, NOV 1981	UNSTEADY PRESSURE DUE TO OSCILLATING CONTROLS OBTAINED FOR TRANSONIC CODE VALIDATION	NASA-TM REPORT PUBLISHED
	3. AGARD 3-D AEROELASTIC STANDARD CONFIGURATIONS DEFINED, JAN. 1982	CONFIGURATIONS PROVIDE PROBLEM DEFINITION FOR COMPARISON CALCULATIONS BY TRANSONIC CODES	AGARD REPORT PUBLISHED
	4. 2-D UNSTEADY AERO COMPUTATIONAL GRID OPTIMIZATION STUDY, APRIL 1982	ESTABLISH EFFECT OF COMPUTATIONAL GRID UPON UNSTEADY CFD RESULTS	STUDY COMPLETED
	5. 2-D FULL FREQUENCY CODE, APRIL 1982	TRANSONIC SMALL PERTURBATION CODE ACCURATE FOR HIGH FREQUENCIES	CODE DEVELOPED
505-33-53	6. EXACT ANALYSIS FORMULATED FOR ASSESSING 2-D LINEARIZED UNSTEADY AERODYNAMICS, APRIL 1982	ASSESSMENT OF ACCURACY OF LINEARIZED TRANSONIC FINITE DIFFERENCE CODES	NASA TM PUBLISHED

Figure 28(a).

UNSTEADY AERODYNAMICS
FY-82 MILESTONES/ACCOMPLISHMENTS (CONTINUED)

RTOP	MILESTONE	SIGNIFICANCE	STATUS
505-33-53	7. ANGLE-OF-ATTACK EFFECTS ON TRANSONIC FLUTTER, MAY 1982	SIGNIFICANCE OF ANGLE-OF-ATTACK AND AIRFOIL SHAPE DEMONSTRATED	AIAA PAPER PUBLISHED
	8. CLIPPED DELTA WING OSCILLATORY PRESSURE TEST DATA ANALYZED, MAY 1982	UNSTEADY PRESSURES OBTAINED FOR TRANSONIC CODE VALIDATION	AIAA PAPER PUBLISHED
	9. DEVELOP HIGHLY ACCURATE NONPLANAR KERNEL FUNCTION APPROXIMATIONS, MAY 1982	EXTENDED ACCURACY OF SUBSONIC UNSTEADY PRESSURE CALCULATIONS	AIAA PAPER PUBLISHED
	10. MODIFIED STRIP ANALYSIS OF ANGLE-OF-ATTACK EFFECTS ON SUPERCRITICAL WING FLUTTER, MAY 1982	COMPARE CALCULATED FLUTTER RESULTS WITH EXPERIMENTAL FLUTTER MEASUREMENTS	AIAA PAPER PUBLISHED
505-33-53	11. DEVELOP STATIC DEFORMATION TRANSONIC AEROELASTIC CAPABILITY, MAY 1982	PREDICT STATIC AEROELASTIC EFFECTS USING FULL POTENTIAL EQUATION CODE	AIAA PAPER PUBLISHED

Figure 28(b).

IMPROVED METHOD FOR TWO-DIMENSIONAL UNSTEADY TRANSONIC FLOW ANALYSIS (XTRAN2L)

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Unsteady Aerodynamics Branch
Extension 2661

RTOP 505-33-53

Research Objective

The objective of this research is to improve the accuracy and utility of finite difference computer programs for unsteady transonic aerodynamic calculations and flutter analysis.

Approach

Several important modifications and additions have been implemented in a transonic finite-difference computer code. Included are an additional unsteady term in the differential equation, a new treatment of the far field boundary conditions, improvement of the transonic algorithm, and development of an improved distribution of points of the finite difference grid.

Accomplishment Description

The program LTRAN2-NLR was limited to low reduced frequencies and sensitive to flow conditions. The ϕ_{tt} term in the complete differential equation was added to the code, allowing accurate calculations for all frequencies. A monotone differencing scheme in the transonic algorithm was incorporated which considerably extended the Mach number and angle of attack range of the program. Nonreflecting boundary conditions were added which allowed a reduction of the extent of the grid and thus reduced computer costs. In addition a new finite difference grid was developed that considerably enhanced the accuracy of the results by eliminating spurious oscillations in the unsteady loads. The program with these modeling improvements is called XTRAN2L. A key factor in developing and assessing the improvements was the implementation of a pulse-transfer function technique based on fast Fourier transforms to obtain unsteady airload frequency response functions from a single transient calculation. This provides airloads for all frequencies of interest with a significant computational savings. Comparisons with exact linear theory results for a flat plate airfoil permits rapid assessment of accuracy of the parameters, such as the grid, being investigated.

The figure gives a sketch of the influence of the grid and nonreflecting boundary conditions. The improved code XTRAN2L is more robust, more accurate, and reduces the computer costs by 33%.

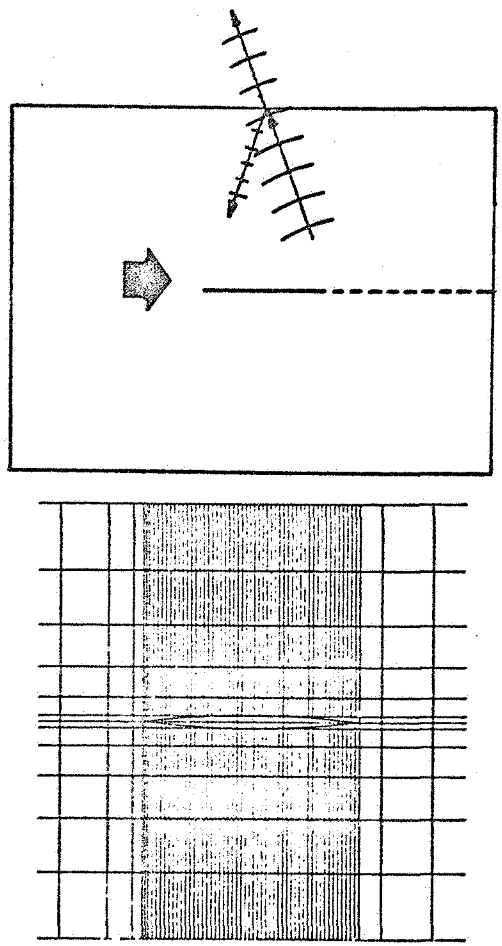
Future Plans

These techniques and improvements will be implemented in the 3-D transonic code XTRAN3S and in a full potential code that is under development. The improvements demonstrated in the 2-D calculations are of great significance for 3-D aeroelastic analysis capability since they enable practical transonic flutter analysis.

Figure 29(a).

IMPROVED METHOD FOR TWO-DIMENSIONAL UNSTEADY TRANSONIC FLOW ANALYSIS (XTRAN2L)

GRID AND
BOUNDARY CONDITIONS



- MORE ACCURATE ANALYSIS
- 50 PERCENT SAVINGS IN COMPUTER COSTS

APPLICATION TO
FLAT PLATE AIRFOIL

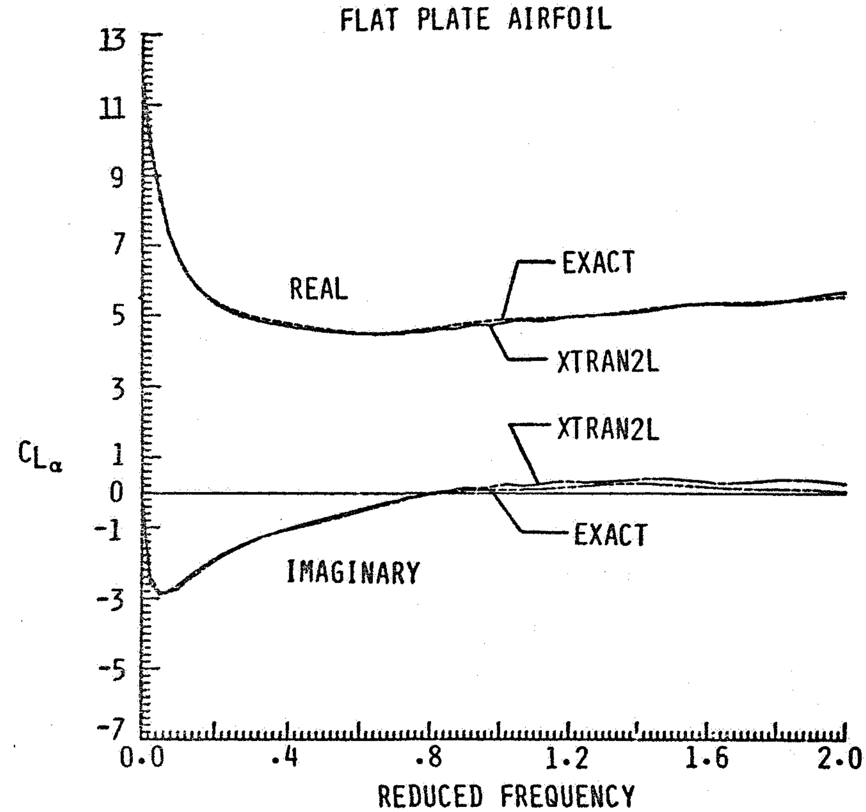


Figure 29(b).

EXPERIMENTAL ANGLE-OF-ATTACK-SENSITIVE FLUTTER STUDIED WITH MODIFIED STRIP ANALYSIS

E. Carson Yates, Jr., Eleanor C. Wynne, Unsteady Aerodynamics Branch and
Moses G. Farmer, Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-33-53

Research Objective. - The objective of this experimental and analytical study is to measure the effects of angle-of-attack on the transonic flutter characteristics of a supercritical wing and to investigate the phenomenological aspects of the observed behavior by use of modified strip analysis.

Approach. - Flutter data for the TF-8A supercritical wing were measured in the TDT for integer values of wing-root angle-of-attack α between 0° and 3°. Since adequate theories for 3D unsteady transonic flow have not yet been developed and verified, flutter calculations corresponding to the test conditions have been made by the modified strip analysis which requires as input spanwise distributions of section lift-curve slope and aerodynamic center. These aerodynamic parameters were obtained from pressure distributions measured in the 8-Foot Transonic Pressure Tunnel with a model that was geometrically similar to but much stiffer than the flutter model.

Accomplishment Description. - Measured flutter boundaries, in terms of flutter-speed index V_I as a function of Mach number M, show a transonic dip of conventional shape for $\alpha = 0^{\circ}$. For nonzero angles-of-attack, however, the measured boundaries curve downward and backward in a manner similar to that observed in supercritical-wing flutter tests at NLR Amsterdam. This unconventional behavior appears to be caused by two factors: (a) viscous effects at low Reynolds number, and (b) static aeroelastic deformation of the flutter model. Decreasing dynamic pressure and hence Reynolds number causes boundary-layer thickening accompanied by changes in shock location. Decreasing dynamic pressure also decreases aeroelastic washout and hence increases section angles of attack. Flutter calculations for values of the mass ratio μ which bracket the experimental values are slightly conservative but in good agreement with the experimental boundary at $\alpha = 0^{\circ}$. At nonzero angles of attack, the calculations do not show the backward turn but indicate instead a double dip similar to that observed in some earlier tests in TDT and in supercritical wing flutter tests recently completed at NLR. It is believed that the backward turn was not calculated because (a) the aerodynamic data available for use in the flutter calculations were obtained at Reynolds numbers much higher than those for the flutter tests; and (b) the aerodynamic model was two orders of magnitude stiffer than the flutter model and hence did not deform nearly as much as the flutter model. Thus, the disagreement between the calculated and experimental results at $\alpha = 2^{\circ}$ is attributed at least in part to differences in mean shape between aerodynamic and flutter models.

Future Plans. - Modified-strip-analysis flutter calculations will be made for the DAST ARW-2 wing in conjunction with pressure-measurement and flutter tests to be conducted in the TDT. A 3-D transonic code will be used to generate the required aerodynamic parameters for a deformed shape that is consistent with the flutter dynamic pressure so that static aeroelastic deformation will be appropriately represented.

Figure 30(a).

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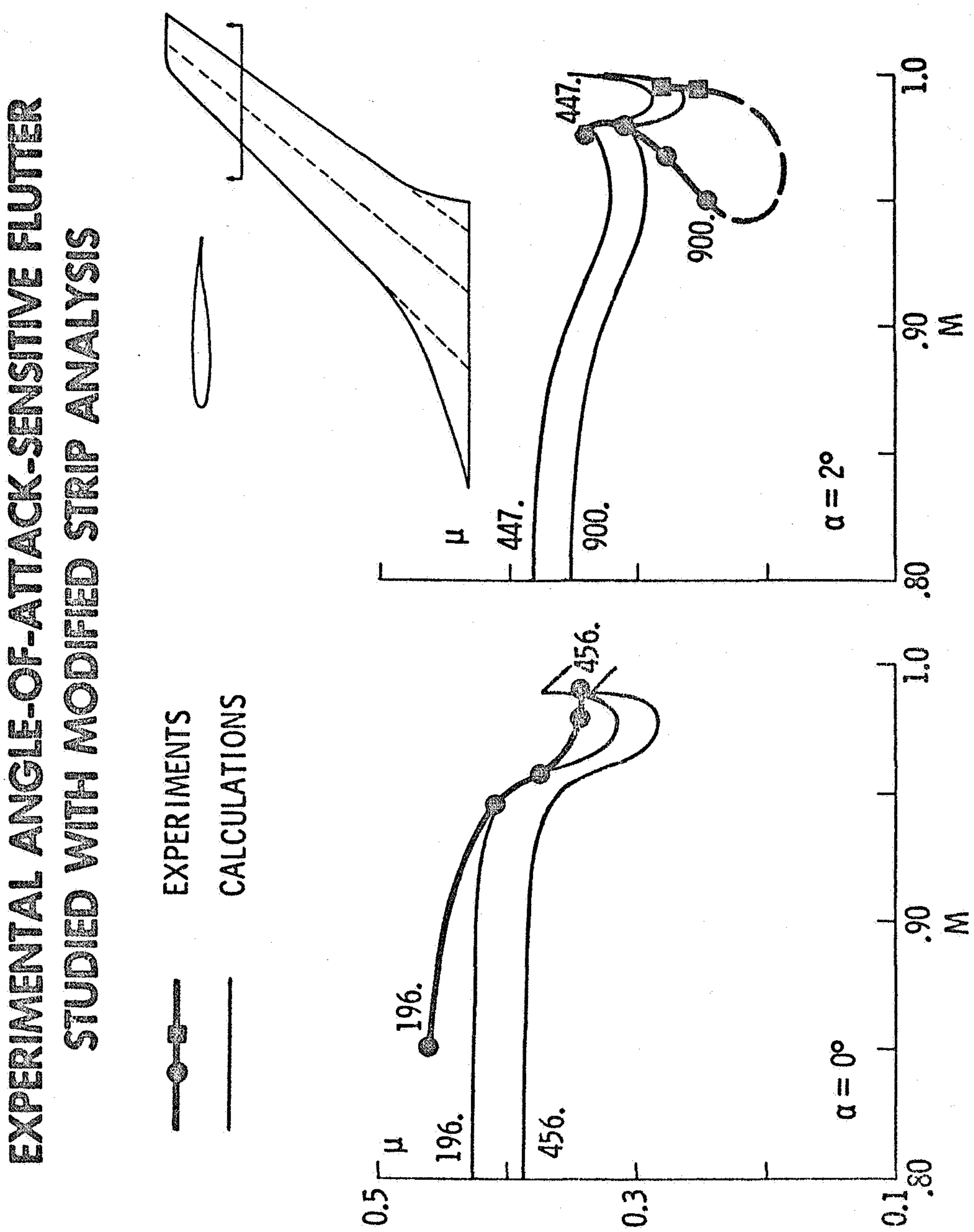

Figure 30(b).

EXPERIMENTAL AND CALCULATED EFFECTS OF ANGLE-OF-ATTACK UPON TRANSONIC FLUTTER

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and
Moses G. Farmer Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-33-53

Research Objective. - The objective of this study is to gain understanding of the transonic flutter mechanism for supercritical airfoils, particularly their behavior as a function of angle-of-attack.

Approach. - Flutter tests of the TF-8A supercritical wing in the TDT have investigated the effect of root angle-of-attack, α_0, upon flutter. Near the design Mach number of 0.98, the flutter boundary, shown on the left of the figure as flutter speed index versus Mach number, was found to curl backwards for angles-of-attack above zero. This curlback occurs for a range of Mach numbers of 0.95 to 1.0. The bottom of the transonic dip could not be determined for $\alpha_0 = 2^0$ because of the difficulty in reducing tunnel pressures to lower values. Since classical unsteady aerodynamic flutter solutions do not predict this novel behavior, an analytical study was conducted to see if a recently developed transonic finite-difference computer code would exhibit the phenomenon. Flutter boundaries of two-dimensional airfoils were calculated using the small perturbation theory HYTRAN2 code for a range of Mach numbers and angles-of-attack, α. The airfoil studied was the supercritical MBB A-3.

Accomplishment Description. - The sketch figure shows a two-dimensional airfoil section mounted on a pitch spring. This simple model is analogous to the effect of washout of angle-of-attack at the tip of a loaded wing. The static nosedown pitching moment, c_m, twists the section from its "root" angle-of-attack, α_0, to a smaller angle, α. The amount of twist is proportional to the total moment and thus to dynamic pressure. When the flutter speed index is plotted versus Mach number for $\alpha = 0$ and 1 deg., a significant transonic dip is seen but there is no evidence of the curl back seen in the TF-8A results. When the effect of static twisting is included and the boundary plotted for "root" angles, α_0, a curl back develops between 2 and 4 degrees. The curl back is due to the static twisting of the airfoil under the combined influences of Mach number and dynamic pressure. Since the flutter speed index is proportional to the square root of dynamic pressure, the nosedown twist angle, $\alpha-\alpha_0$, decreases as the flutter speed index decreases. The resulting higher angles, α, near the bottom of the transonic dip induce transonic effects which produce the curl back of the flutter boundary.

Future Plans. - Continued analysis with the HYTRAN2 code will be conducted to understand how structural parameters and airfoil shape influence the flutter boundaries of 2D airfoils. Flutter analyses of the DAST ARW-2 wing will be performed using both a modified strip theory program and the recently developed XTRAN3S finite-difference program. Also, the right wing panel of the ARW-2 will be tested in the TDT in order to obtain unsteady pressure measurements on an aeroelastic wing and to investigate by subcritical testing the possibility of angle-of-attack sensitive flutter during the flight test program.

Figure 31(a).

TRANSONIC 2D FLUTTER CALCULATIONS EXHIBIT MEASURED ANGLE OF-ATTACK EFFECTS

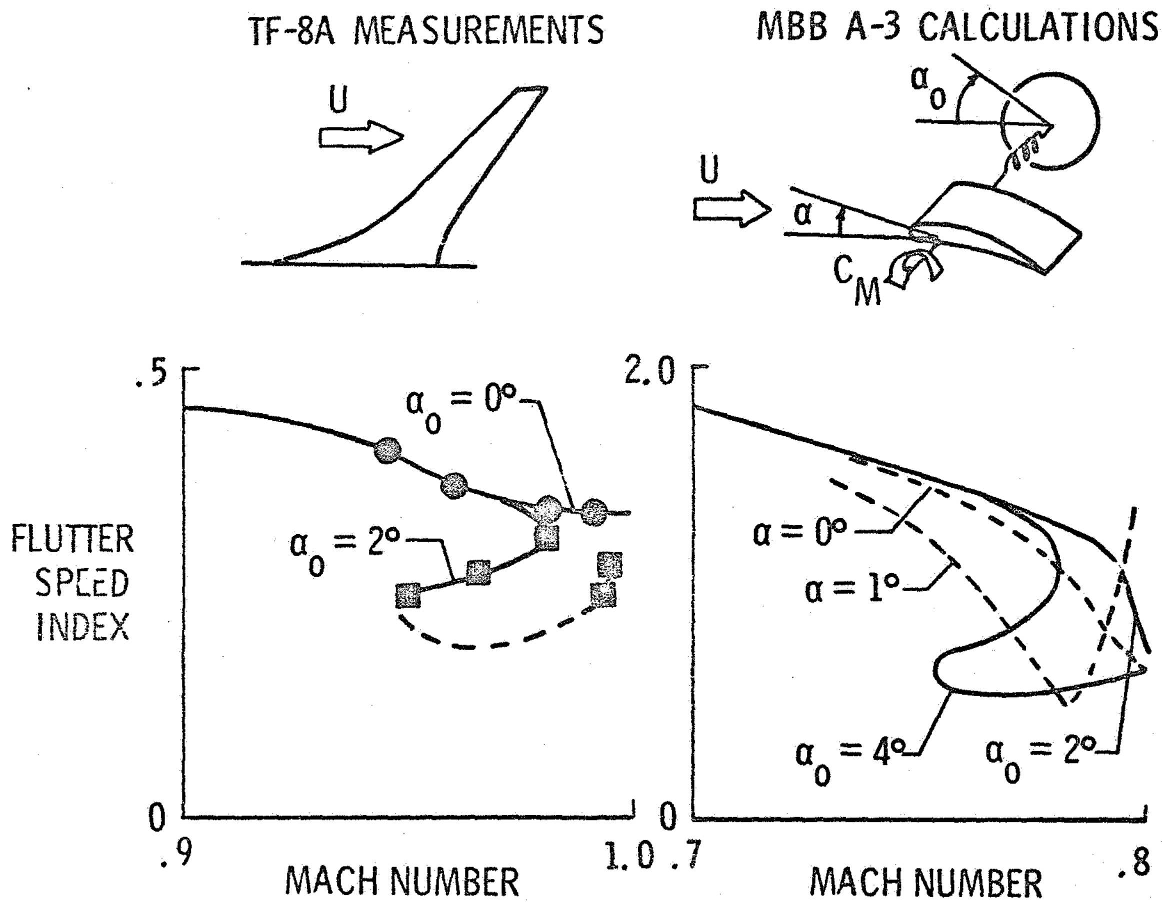

Figure 31(b).

TRANSONIC PRESSURE DISTRIBUTIONS MEASURED ON A RECTANGULAR SUPERCRITICAL WING OSCILLATING IN PITCH

Rodney H. Ricketts and Judith J. Watson
Configuration Aeroelasticity Branch
and
Maynard C. Sandford and David A. Seidel
Unsteady Aerodynamics Branch
Extension 2661

RTOP 505-33-53

Research Objective

The objective of this research is to obtain steady and unsteady transonic pressure data for aiding in the development and early assessment of new analytical computer codes such as XTRAN3S.

Approach

A rectangular wing model having a 12 percent supercritical airfoil section and a panel aspect ratio of two was tested in the Langley Transonic Dynamics Tunnel (TDT) in both freon and air. The model was attached to an electrohydraulic rotary actuator which was used to pitch the model both statically (at angles of attack up to 13 deg) and dynamically (at frequencies up to 20 Hz). In the attached figure the model is shown in the TDT mounted with a splitter plate to divert the tunnel wall boundary layer. The model was constructed with an aluminum center box and lightweight Kevlar composite leading and trailing edges to minimize the model pitch inertia while maximizing the model stiffness. Instrumentation included 123 pressure transducers, 8 accelerometers, and an angle-of-attack potentiometer. The transducers that measured pressures over the aluminum portion of the wing were mounted in the wing surface (in situ). The transducers that measured pressures over the Kevlar portions of the wing were mounted within the wing structure and connected to orifices in the wing surface via tubing of matched lengths (Dutch matched-tubing method).

Accomplishment Description

Steady and unsteady pressures were measured for a large number of model and tunnel conditions in the TDT using freon as the test medium. This is vividly shown in the attached figure which has the wing total lift coefficient plotted against Mach number for a range of angles of attack. For the open symbols, only steady pressure data were acquired. For the closed symbols, both steady and unsteady data were acquired. The unsteady data were measured with the wing oscillating at frequencies of 5, 10, 15, and 20 Hz.

Future Plans

To assess the accuracy and efficiency of the new transonic computer code XTRAN3S, analyses will be made with the code to calculate steady and unsteady pressure distributions for comparison with selected data measured in the tunnel.

Figure 32(a).

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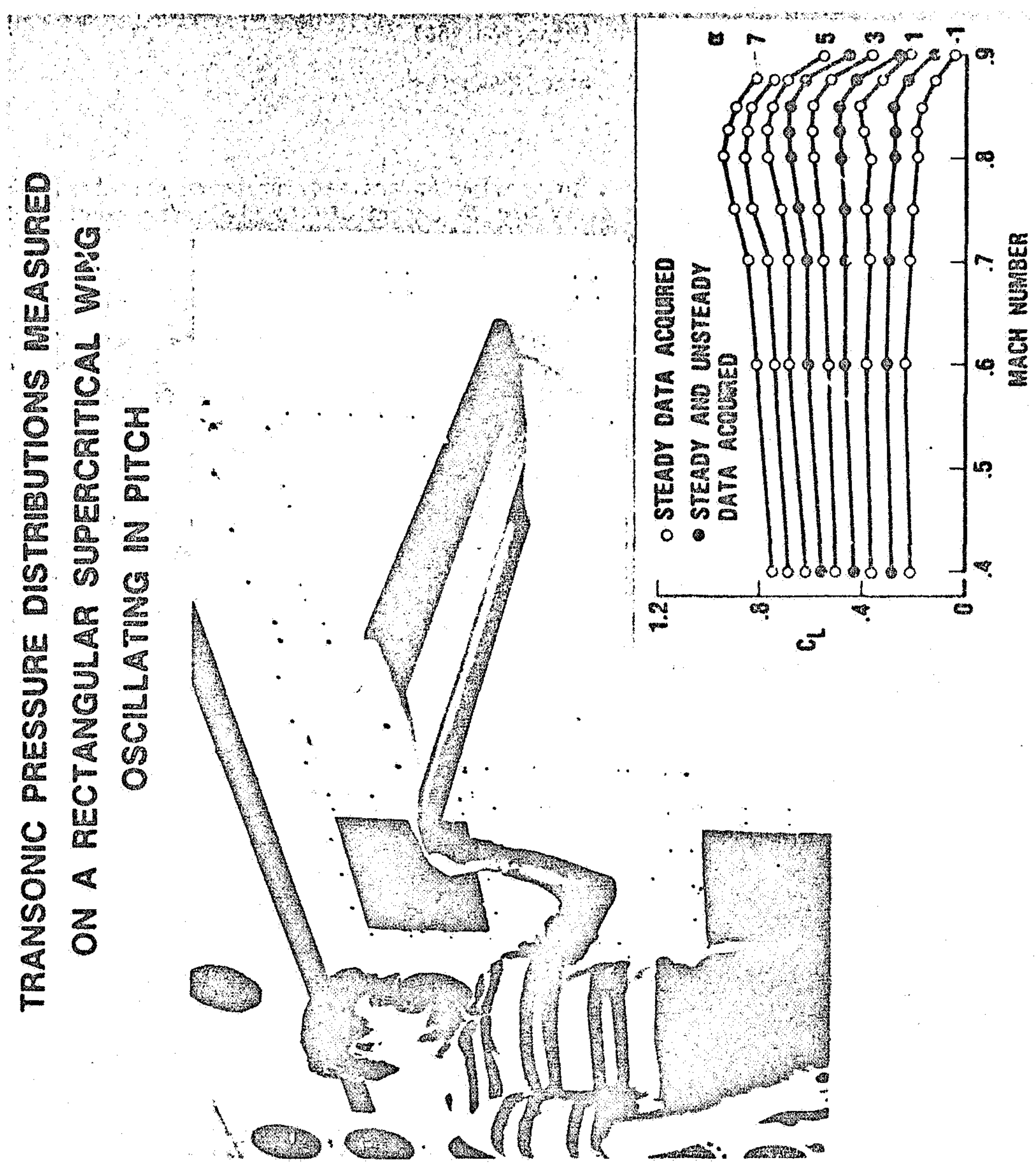

Figure 32(b).

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UNSTEADY PRESSURES MEASURED ON A CLIPPED DELTA WING PROVIDE DATA FOR TRANSONIC CODE VALIDATION

R. W. Hess and E. C. Wynne, Unsteady Aerodynamics Branch
and
F. W. Cazier, Jr., Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-33-53

Research Objective

The objective of the program is to provide an unsteady pressure data base for validating transonic computer codes and to contribute to the understanding of complex transonic flow phenomena.

Approach

An instrumented clipped delta wing with a six percent circular arc airfoil and a trailing edge control surface was constructed. Data was obtained for the wing oscillating in pitch and for control surface oscillations for wing mean angles-of-attack of up to six degrees.

Accomplishment Description

Static and oscillating pressures were measured over a range of Mach numbers from 0.4 to 1.12 in the TDT in Freon at a Reynolds number of 10 million. Some 1200 total data points were measured during the test. Data sets were taken at each test Mach number at which the mean angle-of-attack and the frequency of the wing pitch oscillations were varied as well as the amplitude and frequency of the trailing edge control surface. For steady angles-of-attack less than 3 degrees, the measured static pressure distributions for both wing at angle of attack and control surface deflections are in good agreement with calculations from a transonic small disturbance code. At angles-of-attack greater than 3 degrees, the formation of a leading edge vortex was observed. Good agreement is shown between experimental and calculated pressure at 2 degrees and the disagreement due to the leading edge vortex at 4 degrees. Over the center portion of the chord C_p/degree is about 0.1. On the right side of the figure the unsteady pressure magnitude is shown for oscillations in pitch of ± 0.5 degrees about these mean angles. The presence of the shock at 70% chord and the leading edge vortex for the 4 degree data are evident. Over the center portion of the chord $|C_p|$/deg.-oscillation is about 0.1. Transonic unsteady aerodynamic codes capable of treating highly swept and tapered three-dimensional wings such as this wing will be available in the near future. This data set will be of primary importance in validating such codes.

Future Plans

The data will be presented in two reports; one dealing primarily with the unsteady vortex generated pressure at M = 0.4; and another presenting the transonic results from M = 0.88 to M = 0.96. There are plans to use the wing for an additional test to measure static and unsteady pressures induced on the wing by an oscillating canard. The canard has been fabricated of carbon-epoxy skin spars and ribs and is nearly complete.

Figure 33(a).

MEASURED PRESSURES ON CLIPPED DELTA WING

M = 0.9 , 69.8 % SPAN

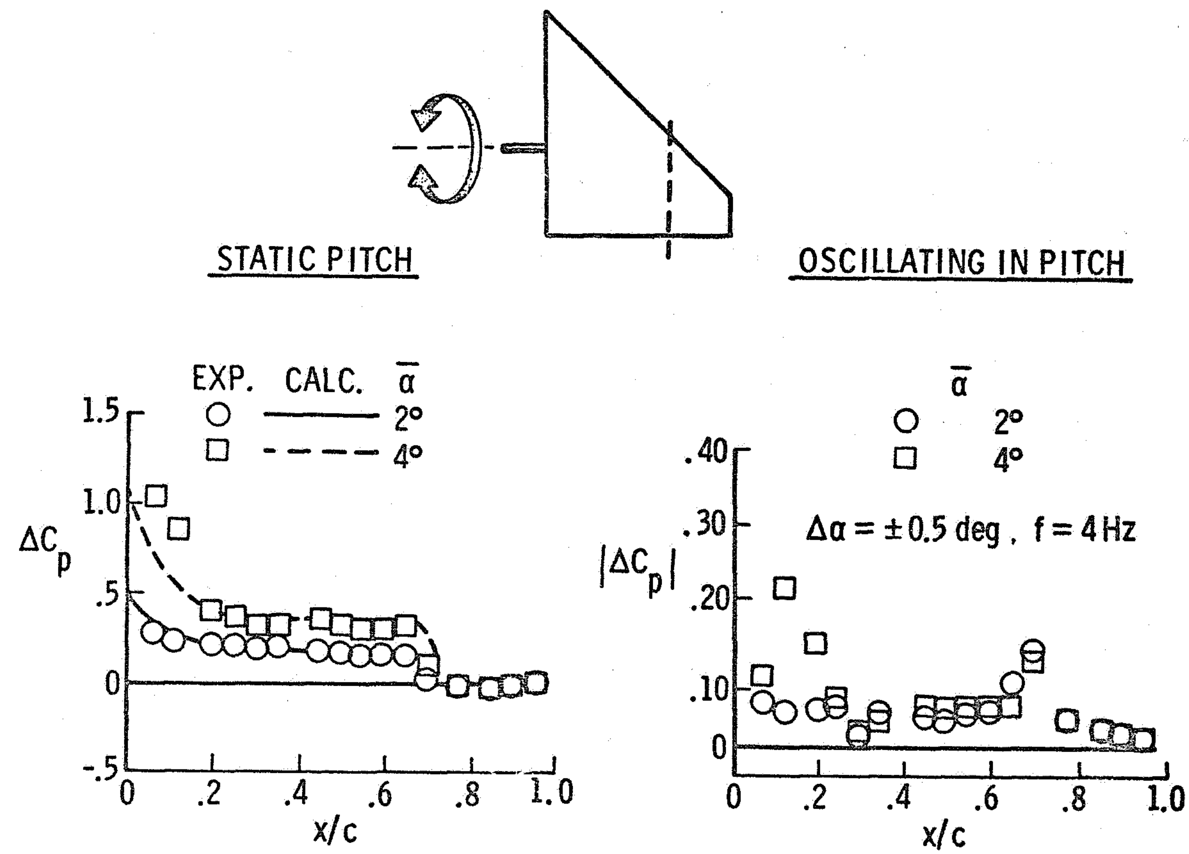

Figure 33(b).

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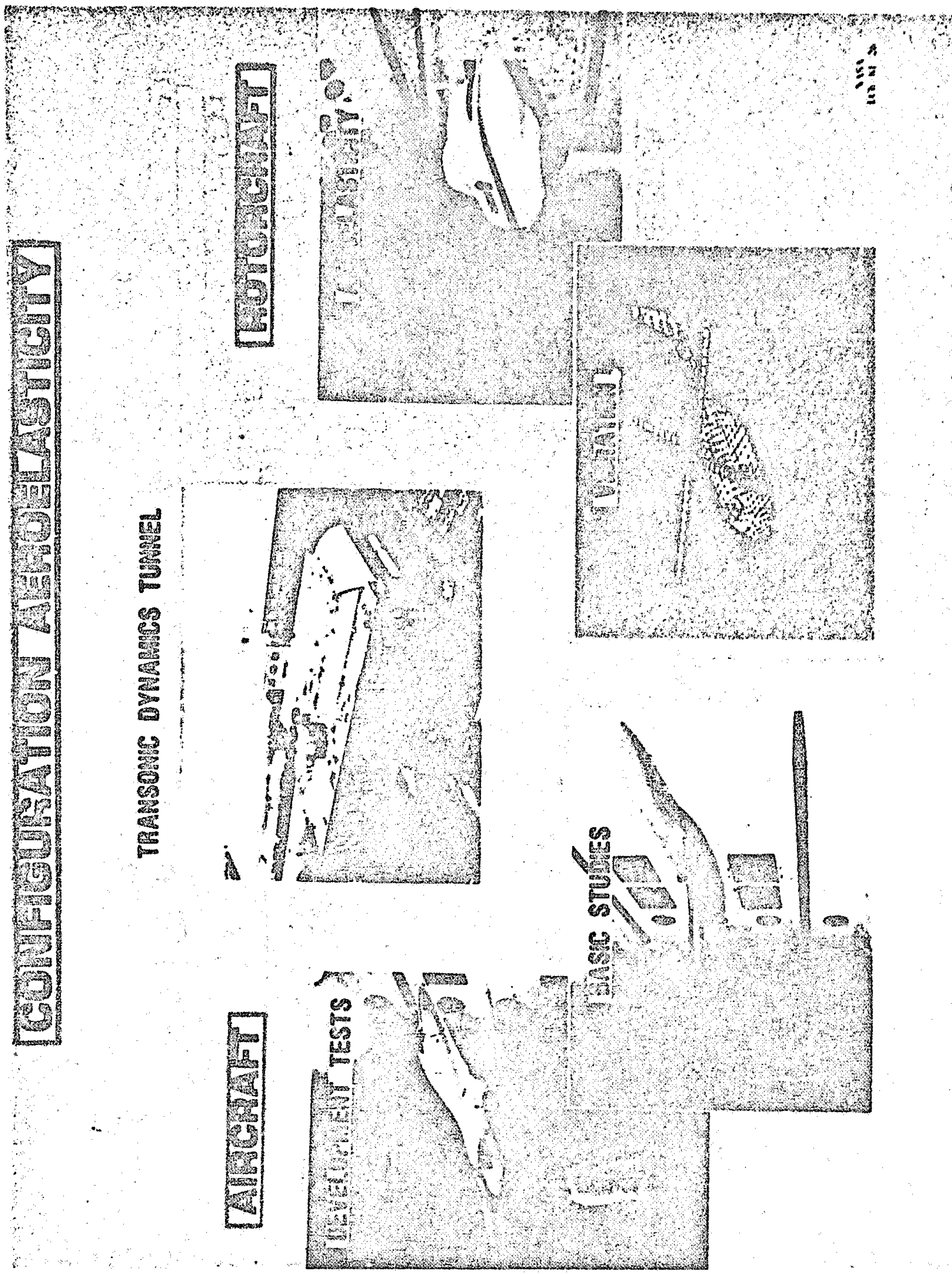

Figure 34.

CONFIGURATION AEROELASTICITY
5 YEAR PLAN

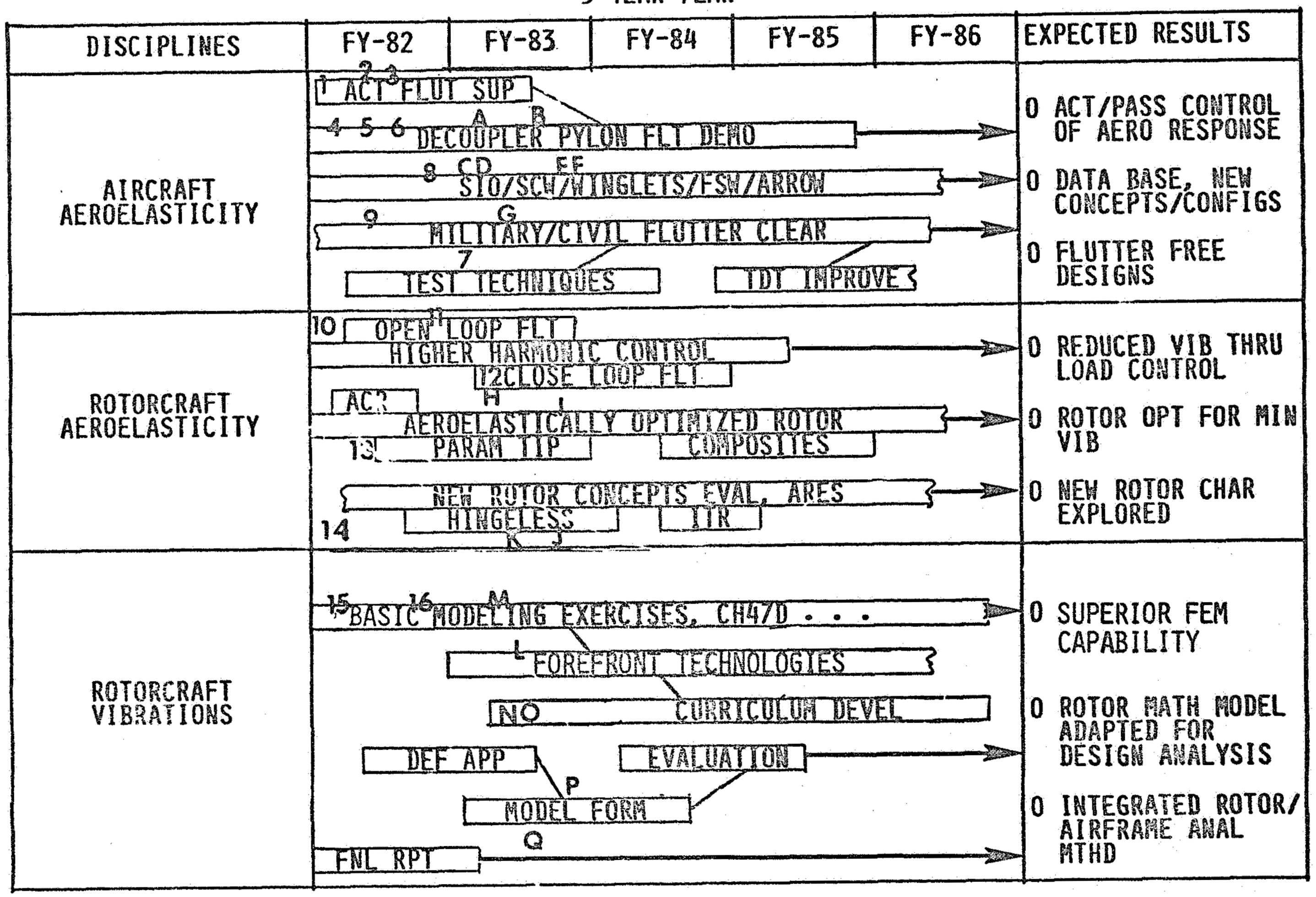

Figure 35.

CONFIGURATION AEROELASTICITY
FY-82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
1	505-43-33	COMPLETE WING/STORE FLUTTER SUPPRESSION TESTS USING F-16 MODEL, 10/'82	DETERMINES EFFECTIVENESS OF ACTIVE FLUTTER SUPPRESSION SYSTEMS IN INCREASING FLUTTER SPEED OF F-16 AIRPLANE	SUCCESSFULLY COMPLETED ON SCHEDULE
2	505-43-33	COMPLETE WING/STORE FLUTTER SUPPRESSION TESTS USING YF-17 MODEL (PHASE I), 11/'81	DETERMINES EFFECTIVENESS OF DIGITAL ACTIVE FLUTTER SUPPRESSION SYSTEMS	SUCCESSFULLY COMPLETED ON SCHEDULE
3	505-43-33	COMPLETE WING/STORE FLUTTER SUPPRESSION TESTS USING YF-17 MODEL (PHASE II), 4/'82	DETERMINES EFFECTIVENESS OF ADAPTIVE DIGITAL ACTIVE FLUTTER SUPPRESSION SYSTEM WHEN STORES ARE EJECTED	SUCCESSFULLY COMPLETED ON SCHEDULE
4	505-33-53 533-02-73	AWARD CONTRACT FOR DESIGN AND FABRICATION OF DECOUP-LER PYLON FOR FLIGHT TESTS, 1/'82	FABRICATION OF DECOUPLER PYLON FOR FITTING TO F-16 AIRPLANE	COMPLETED
5	505-33-53 505-02-73	COMPLETE PRELIMINARY DESIGN REVIEW FOR DECOUPLER PYLON, 6/'82	EVALUATES DESIGN CONCEPT FOR DECOUPLER PYLON	COMPLETED
6	505-33-53 505-02-73	COMPLETE CRITICAL DESIGN REVIEW FOR DECOUPLER PYLON, 9/'82	EVALUATES FINAL DESIGN OF DECOUPLER PYLON	COMPLETED
7	505-33-53	COMPLETE DESIGN OF FLUTTER MODELS FOR 0.3M CRYO TUNNEL, 6/'82	DETERMINES EFFECTS OF REYNOLDS NUMBER ON FLUTTER	DELAYED BECAUSE OF LACK OF MANPOWER, INITIATED WORK 6/'82
8	533-02-83	INITIATE STUDY OF AERO-SERVO-ELASTIC INSTABILITIES OF FORWARD-SWEPT (FSW) CONFIGU-RATIONS, 7/'82	PROVIDES EXPERIMENTAL DATA FOR CALIBRATING ANALYSES BEING USED TO DEVELOP FSW FLIGHT DEMONSTRATOR	CONTRACT FOR MODEL FABRICATION AND ANALYSIS AWARDED

Figure 36(a).

CONFIGURATION AEROELASTICITY
FY-82 MILESTONES/ACCOMPLISHMENTS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
9	505-43-33	COMPLETE F-16E FLUTTER CLEARANCE STUDIES USING FULL SPAN MODEL, 3/'82	DEMONSTRATES THAT NEW ARROW WING F-16E AIRPLANE IS FLUTTER FREE AT TRANSONIC SPEEDS	SUCCESSFULLY COMPLETED ON SCHEDULE
10	505-42-13	COMPLETE EVALUATION OF PENDULUM VIBRATION, ABSORBER 10/'81	DETERMINES ADVANTAGES AND DISADVANTAGES OF TECHNIQUE FOR REDUCING HELICOPTER ROOT MOMENTS AND SHEARS	COMPLETED, RESULTS PUBLISHED
11	505-42-13	COMPLETE INITIAL HIGHER HARMONIC CONTROL (HHC) FLIGHT TESTS, 10/'81	DEMONSTRATES HHC AS MEANS FOR REDUCING HELICOPTER FUSELAGE VIBRATIONS	DELAYED BECAUSE OF CONTROL SYSTEM FLEXIBILITY. OPEN-LOOP TESTS COMPLETED, 8/'82
12	505-42-13	COMPLETE SECOND SERIES OF HIGHER HARMONIC CONTROL (HHC) FLIGHT TEST, 8/'82	EVALUATES ALTERNATE CONTROL LAWS AND NOISE	POSTPONED, NO NEW DATE SET
13	505-42-13	COMPLETE PARAMETRIC TIP STUDY USING ARES MODEL, 2/'82	IDENTIFIES POSITIVE AND NEGATIVE FACTORS THAT AFFECT AEROELASTICALLY CONFORMABLE ROTOR	SUCCESSFULLY COMPLETED ON SCHEDULE
14	505-42-13	COMPLETE CHECKOUT OF HINGELESS ROTOR ON ARES MODEL IN HOVER FACILITY, 12/'81	PRECURSOR STUDIES TO SUPPORT WIND-TUNNEL TESTS	SUCCESSFULLY COMPLETED, 11/'81
15	505-42-13	COMPLETE DEFINITION TEST REQUIREMENTS FOR CH-47D VALIDATION TESTS, 10/'81	ESTABLISHES TECHNICAL APPROACH FOR VALIDATION TESTS	COMPLETED ON SCHEDULE
16	532-06-13	COMPLETE CH-47D VALIDATION TESTS, 7/'82	PROVIDES EXPERIMENTAL DATA TO VALIDATE FINITE-ELEMENT ANALYTICAL MODEL	SUCCESSFULLY COMPLETED ON SCHEDULE

Figure 36(b).

VERTICAL TAIL OF NEW SUPERSONIC CRUISE FIGHTER AIRPLANE (F-16E) SHOWN FREE FROM TRANSONIC FLUTTER

Charles L. Ruhlin and Judith J. Watson
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-43-33

Research Objective

A new supersonic cruise version of the F-16 fighter airplane, designated the F-16E (formerly F-16XL or SCAMP), is being developed by the General Dynamics/ Ft. Worth Division. It features an advanced technology wing that offers significantly improved aerodynamic performance over the present F-16 airplane. This wing has a cranked arrow-wing planform with highly refined camber and twist distributions, and uses lightweight graphite composites for the main wing skin structure. Two existing F-16 airplanes are being modified to an F-16E configuration for early flight demonstration purposes, with first flight scheduled for mid-1982. The modifications include replacing the present F-16 wing with the new F-16E wing, lengthening of the fuselage by 1.42 m (56 inches), and removing the horizontal tail (the F-16E will be controlled longitudinally by wing elevons). These F-16E airplanes will use the same basic vertical tail as the Norwegian F-16 airplane, which has a drag-chute pod, but with rudder and rudder actuator stiffened slightly.

Approach

As part of the flutter clearance for these F-16E airplanes, a series of transonic flutter tests of 1/4-size models will be made in the Transonic Dynamics Tunnel (TDT). Critical tests to demonstrate the flutter clearance of the F-16E vertical tail configuration (the first tests in the series) were recently concluded. The attached figure shows the tested configuration and in the insert, a side view of the vertical tail model. The purpose of these tests was to determine if the aerodynamic flow associated with the new arrow-wing could affect the flutter of the vertical tail sufficiently to reduce the flutter margin of safety required for flight. The model fuselage was mounted to a sting that extended forward into the simulated engine exhaust duct. The vertical tail model closely represented the dynamic characteristics of the full-scale article, but the model wings and fuselage were somewhat overstiff. Another feature of this model that had some influence on the dynamics and aerodynamics of the vertical tail is the drag-chute pod, whose trailing-edge fairing is located at the base of the tail.

Accomplishment Description

The TDT flutter tests indicated that the vertical tail was free from flutter up to speeds greater than 20 percent above the limit flight speed envelope.

Future Plans

No additional work is planned, but as the F-16E airplane development program evolves there may be requirements for additional tests.

Figure 37(a).

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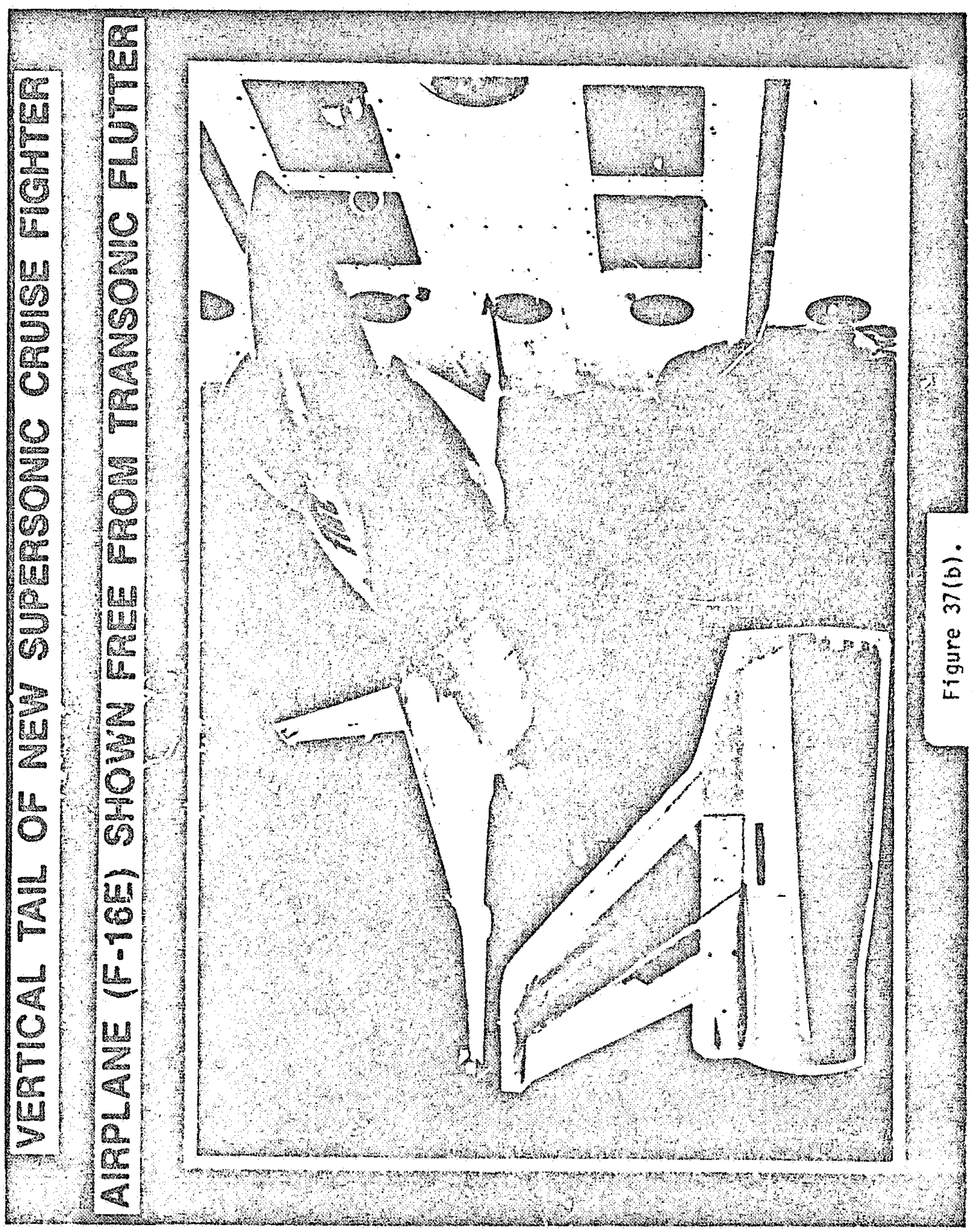

Figure 37(b).

NEW F-16E FIGHTER CONFIGURATIONS FLUTTER CLEARED IN TDT FOR FLIGHT DEMONSTRATION TESTS

Judith J. Watson and Charles L. Ruhlin
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-43-33

Research Objective

The objective of this test in the Langley Transonic Dynamics Tunnel (TDT) was to provide experimental flutter data to support the flight-demonstration tests of the new F-16E fighter airplane. This support was requested by the U. S. Air Force in preparation for flight tests scheduled to start during the summer of 1982.

Approach

The 1/4 size, complete-airplane, dynamically scaled flutter model of the F-16E used in the present test was built by the General Dynamics/Ft. Worth Division. This model was mounted on a two-cable support system in the TDT and tested over a scaled range of Mach numbers and dynamic pressures that provided at least a 20% flutter margin of safety. Two views of the model in the TDT are shown on the attached figure. The configurations tested were the primary flight-test airplane configurations and included different combinations of underslung external ordnance types which were indicated by analysis to be the most susceptible to flutter.

Accomplishment Description

Fourteen different wing-store configurations, as well as the baseline airplane flight configuration, were shown to exceed the flutter margin of safety up to a maximum test Mach number of 1.10. The model properties compared favorably to the scaled mass and stiffnesses of the airplane, but final adequacy of the vibration characteristics of the model remain to be proven by comparison with the measured data from the ground vibration test (GVT) of the airplane scheduled for June 1982. These wind-tunnel test results provided confidence in the analytical flutter prediction techniques and allowed a significant reduction in the number of expensive flight flutter and ground vibration test hours.

Future Plans

This was the second of three planned TDT entries in support of the F-16E flutter design development. The third TDT entry is scheduled for February 1983 to flutter-clear additional store configurations and, if needed, to confirm previously cleared configurations with the model updated to more closely match the airplane vibration characteristics measured in the GVT.

Figure 38(a).

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NEW F-16E FIGHTER CONFIGURATIONS FLUTTER CLEARED
IN TDT FOR FLIGHT DEMONSTRATION TESTS

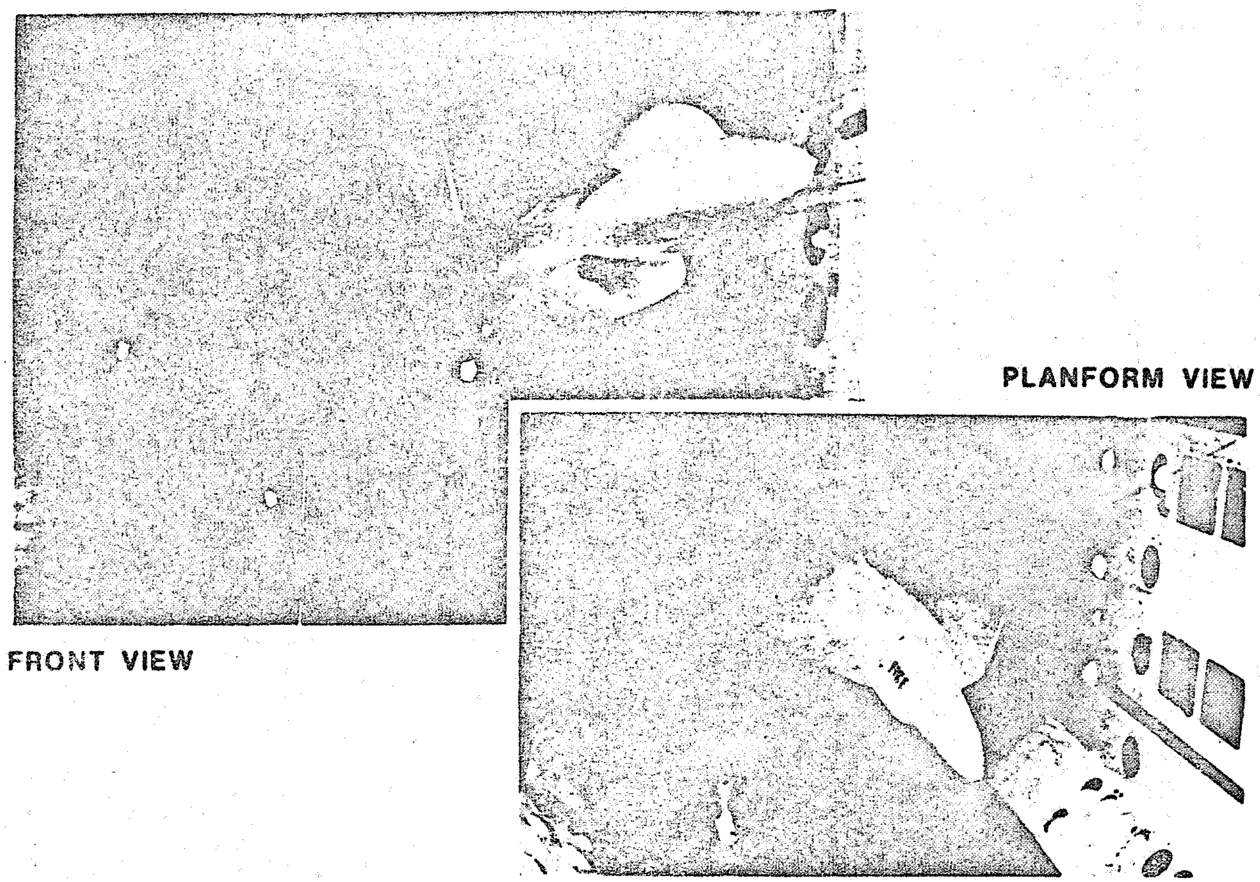

Figure 38(b).

F-16 FLUTTER SUPPRESSION SYSTEMS EVALUATED IN TDT TESTS

F. W. Cazier, Jr.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-43-33

Research Objective

Modern fighter aircraft carry many types and combinations of external wingmounted stores. It is highly probable that the carriage of some of these stores will result in flutter speeds which are well within the desired operational envelope of the aircraft. One approach to avoiding a restricted envelope is the use of an active control system to suppress the wing/store flutter. An active control system operates by sensing wing or store motion with suitable transducers and feeding back these signals through appropriate control laws to drive control surfaces. Properly driven, the control surfaces provide aerodynamic forces and damping to suppress flutter.

Approach

Recently, the F-16 flutter model with an ctive Flutter Suppression System (FSS) was tested in the TDT in a joint USAF/NASA test. In the figure the 1/4-scale F-16 that was tested is shown installed on the cable mount system. Flutter results were obtained for two stores configurations, one having a symmetric flutter mode and one having an antisymmetric flutter mode. Initially, the flutter boundaries of the F-16 with stores and no FSS were determined, and an appropriate control law was developed for each configuration. Then the effectiveness of the active control systems in increasing the flutter speeds was determined.

Accomplishment Description

Three significant achievements were obtained during tests of the antisymmetric flutter suppression system which was developed for the stores configuration with the antisymmetric flutter mode. First, with the FSS engaged, the model was tested at conditions well above the unaugmented flutter boundary without encountering flutter. While no attempt was made to determine a maximum increase in velocity or dynamic pressure obtainable, increases in dynamic pressure in excess of 100 percent at $M = 0.8$ were demonstrated for antisymmetric flutter. A 45-percent increase in dynamic pressure at Mach number 0.95 was demonstrated for the symmetric case. Second, the model was flown at the same test conditions above the flutter boundary with the control surface disabled on one wing, simulating a failed actuator. Although the damping was reduced, indicating that stability margins were less for this failed actuator case, the original control law was still effective in preventing flutter up to flight conditions tested for the fully effective actuator case. Third, frequency response methods were used to estimate FSS gain and phase margins for the basic system. These estimated margins were verified experimentally by independently changing the control law until flutter occurred. In general, the gain and phase margins exceeded the desired ± 6 DB gain margin and ± 45 degrees phase margin.

Future Plans

This work is complete.

Figure 39(a).

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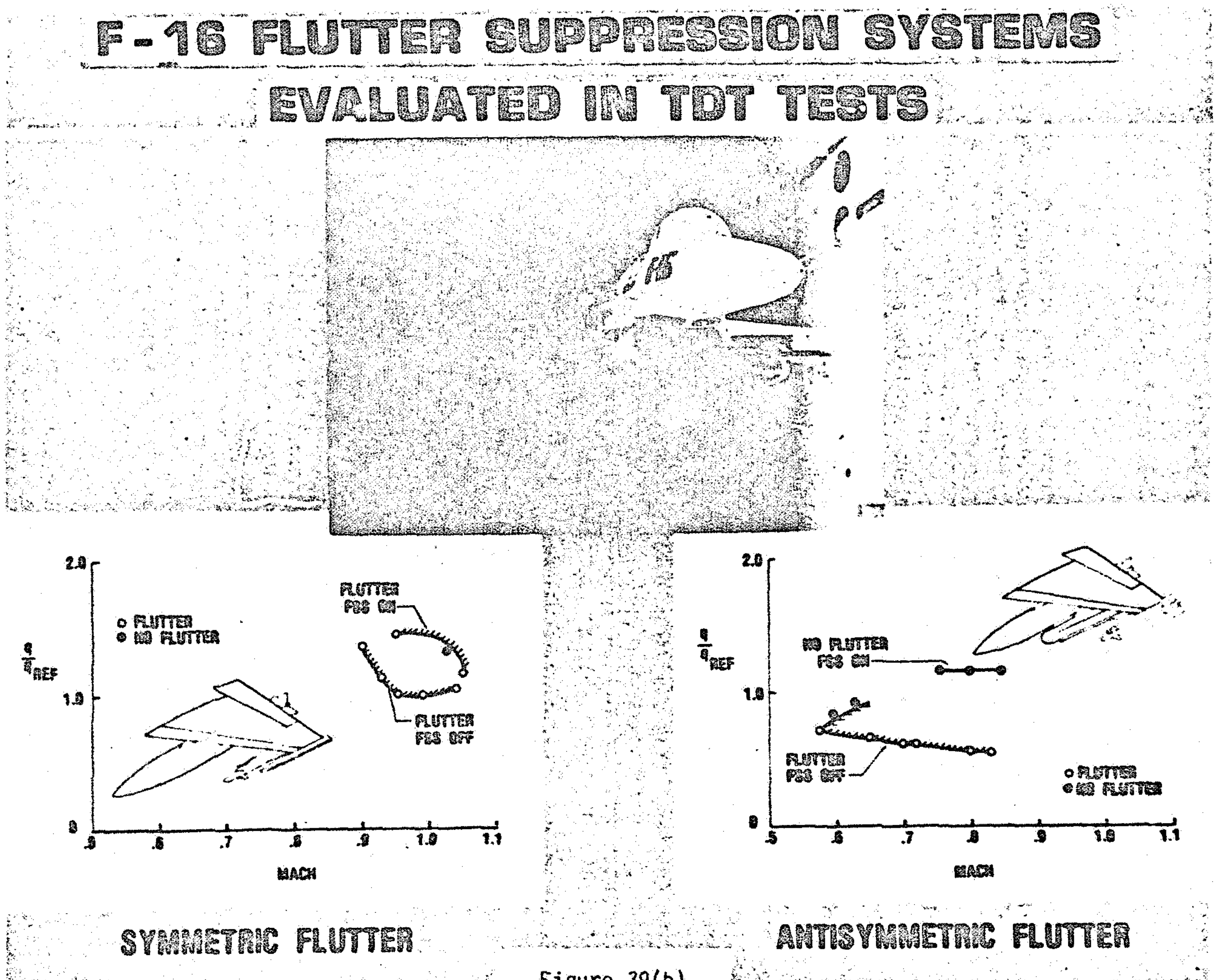

Figure 39(b).

DIGITAL ACTIVE FLUTTER SUPPRESSION SYSTEMS DEMONSTRATED IN TDT TESTS

Moses G. Farmer and Judith J. Watson
Configuration Aeroelasticity Branch
Extension 2661

RTOP's 505-43-33 and 505-33-53

Research Objective

Fighter aircraft are required to carry a large variety of external wing-mounted stores. Some store configurations cause reductions in flutter speed, and, as a consequence, place restrictions on the aircraft's operating envelope. To avoid such restrictions, considerable research by NASA, the Air Force, and industry has gone into the development and wind-tunnel testing of methods of active flutter suppression. The basic approach is to sense motion of the wing using several accelerometers, send the accelerometer signals to a computer which implements a control law, and then feed the control law output to one or more hydraulically-actuated control surfaces which move to provide aerodynamic damping to suppress flutter.

Approach

As part of a NASA/AFWAL cooperative research program on wing/store flutter suppression, tests were conducted in the Langley Transonic Dynamics Tunnel (TDT). The test bed was the same Northrop-built YF-17 model used in previous TDT entries. This semi-span model is shown in the attached figure. For this study, control laws that previously have been implemented using an analog computer were implemented with a digital computer. This was done because on aircraft it is desirable to use the more versatile existing digital computers.

Accomplishment Description

Flutter results were obtained at a constant Mach number. These data show how damping in the flutter mode decreased as dynamic pressure was increased for the cases of inactive flutter suppression system (open loop) and closed loop with the same control law implemented first by an analog computer and then by a digital computer. Flutter occurs when the damping decreases to zero. It can be seen that the digital data agree very well with the analog data and that in both cases the projected flutter dynamic pressure is about twice the value projected for the open loop condition. An additional achievement of this most recent test was the development of a method for capturing a tip missile when it was ejected from the model. It can be seen that two steel cables were threaded through the tip missile--one at each end. Each cable was attached to the ceiling and floor of the test section. When the missile was ejected, it slid down the cables to shock absorbers which prevented the missile from striking the floor. This ejection/capture system was developed for use in follow-on tests of adaptive flutter suppression systems.

Future Plans

This study was the first phase of a two phase study of digital/adaptive active flutter suppression. Both phases are now complete.

Figure 40(a).

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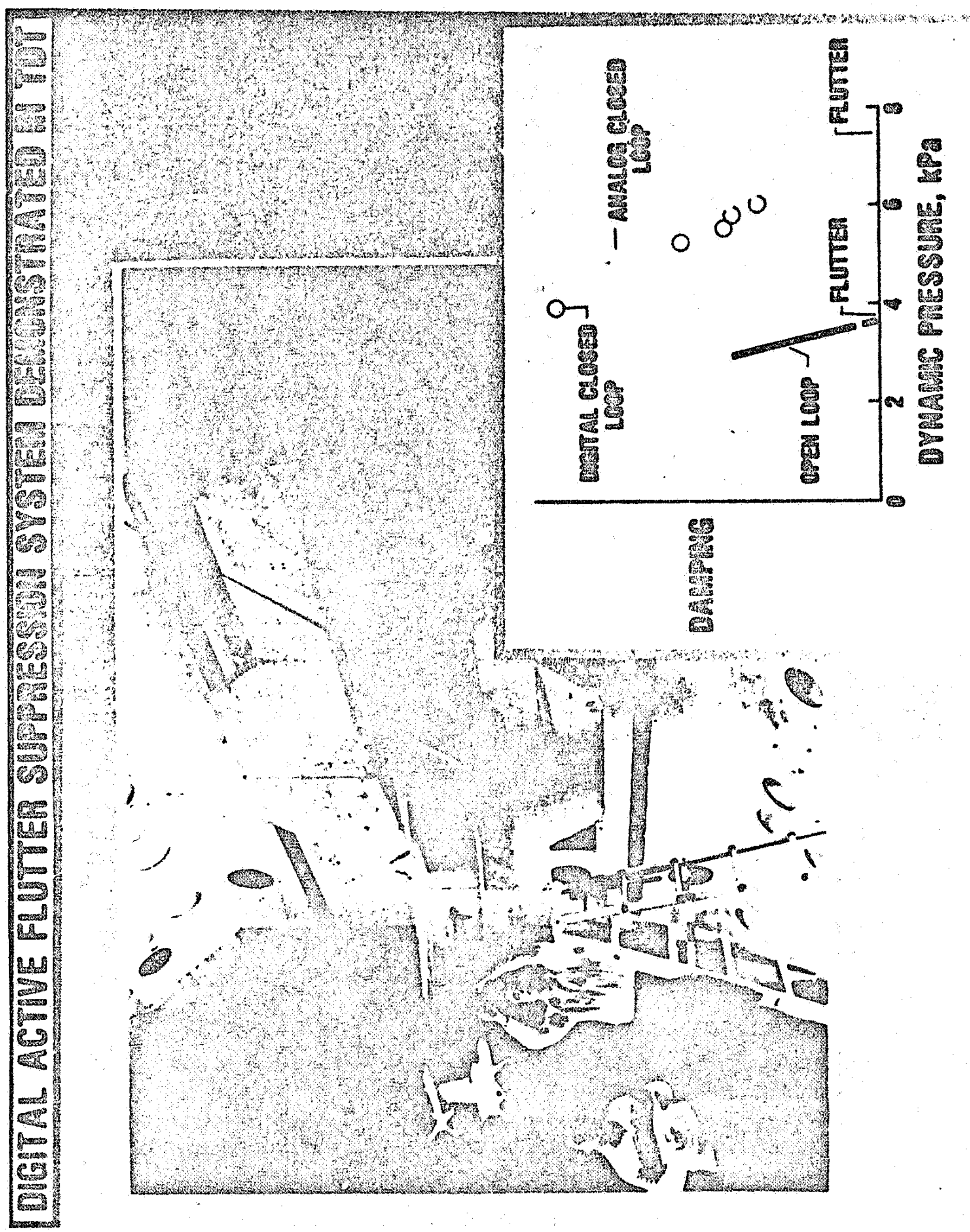

Figure 40(b).

AN ADAPTIVE DIGITAL ACTIVE FLUTTER SUPPRESSION SYSTEM DEMONSTRATED IN TDT TESTS

Moses G. Farmer
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-43-33

Research Objective: The objective was to perform the first experimental demonstration of the concept of adaptive flutter suppression. This concept will be very useful when active flutter suppression is applied to fighter aircraft for which sudden changes in configuration occur when stores are launched or ejected.

Approach: The most recent test in a series of NASA/AFWAL cooperative research programs on wing/store flutter was conducted in the TDT during April 1982. The test bed was the same Northrop-built YF-17 model used in previous TDT entries. Nonadaptive flutter suppression has been studied in previous tests using first analog and then digital computers. The basic approach is to sense motion of the wing using several accelerometers, send the accelerometer signals to a computer on which a specific control law is programmed, and then feed the control law output to one or more hydraulically actuated control surfaces which move to provide aerodynamic damping to suppress flutter. The concept of adaptive flutter suppression requires that the response of the wing be continuously monitored to determine its stability. When the approach to an instability is determined from analysis of the response data, the computer generates a control law to provide the needed stability. As the wing response changes, either slowly because of changes in Mach number and dynamic pressure or rapidly because of ejecting an external store, the computer quickly adapts (modifies) the control law to ensure that stability is maintained.

Accomplishment Description: The use of adaptive flutter suppression was demonstrated by ejecting a wing tip missile at a tunnel flow condition that was above the flutter boundary for the wing without the tip missile. Two steel cables were threaded through the tip missile--one at each end. Each cable was attached to the ceiling and floor of the test section. When the missile was ejected it slid down the cables to shock absorbers which prevented the missile from striking the floor. In this way the missile was captured and saved from destruction. The data are oscillograph records which show oscillations of the wing and control surface. Before the missile was ejected, neither the wing or control surface was moving significantly. When the missile was ejected, the wing began to flutter. The digital computer first sensed that the wing oscillatory motion had become unstable, then activated a control law and stabilized the motion, producing a no-flutter situation as indicated by the decaying oscillations of the wing bending response.

Future Plans: This study concludes the planned wind-tunnel test program on adaptive flutter suppression. Currently, the Air Force is planning a flight demonstration of these adaptive techniques near the end of this decade.

Figure 41(a).

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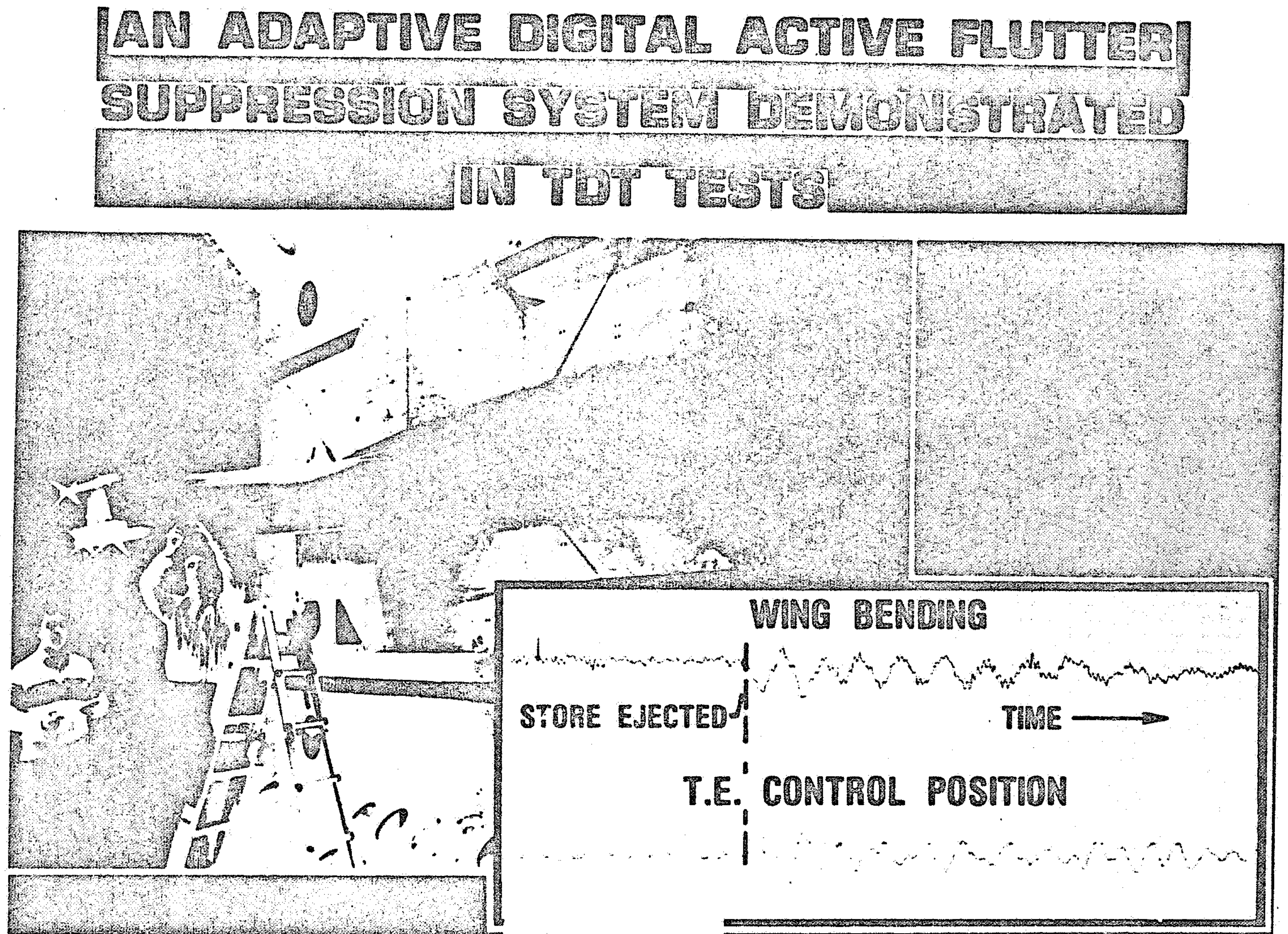


Figure 41(b).

FLUTTER OF AEROELASTICALLY TAILORED QUICK-ROLL WING PREDICTABLE BY CONVENTIONAL ANALYSIS

Charles L. Ruhlin and Judith J. Watson
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-43-33

Research Objective: The use of fiber composites in aircraft structures offers not only high strength and stiffness for low weight but also the capability of aeroelastically tailoring lifting surfaces for improved aircraft performance. Aeroelastic tailoring is the stiffness design of a surface so that it elastically deforms (primarily twists) during flight to a shape that provides the desired aerodynamic load distribution. The tailoring is possible because the fibers have directional properties and can be sized and oriented to obtain specific directional stiffness characteristics. Because aeroelastic tailoring of the stiffness affects the vibration mode characteristics as well as the aerodynamic loading, there was concern regarding the flutter behavior of such tailored surfaces and the adequacy of conventional flutter analyses to predict their behavior.

Approach: A joint Air Force/NASA research investigation was undertaken therefore to measure the transonic flutter characteristics of an aeroelastically tailored wing for correlation with analyses. Selected for study was a fighter airplane wing design that was comparable to an F-16 airplane wing and that was aeroelastically tailored to have a high wing tip loading (wing washin). Washin increases the aileron effectiveness and allows an airplane to be rolled at a faster rate (quick-roll capability). A 1/4-size, semispan flutter model was designed and built by General Dynamics/Ft. Worth (GD/FW) under Air Force contract. The model was tested cantilever-mounted in the TDT at Mach numbers from 0.65 to 1.15. The black bands on the model are graphite fiber strips that were bonded to the fiberglass skin to obtain the tailored stiffnesses.

Accomplishment Description: The transonic flutter characteristics measured for this washin wing model appeared quite usual with a dip in the flutter boundary occurring near a Mach number of 0.9. The experimental flutter points were estimated from damping trends established from the model responses in the region below the flutter boundary thus reducing the risk of losing the model at flutter. Flutter analyses were made at Mach numbers up to 0.9 using subsonic kernel function lifting surface theory with measured vibration mode shapes and frequencies. The agreement between the measured and calculated subsonic flutter results is considered good. Additional analyses by GD/FW indicated that vibration mode shapes and frequencies calculated using NASTRAN agreed fairly closely with the measured data and that the model flutter characteristics calculated using these NASTRAN model data agreed reasonably with the experimental results. In summary, for this quick-roll (washin) configuration, the flutter was predictable at subsonic speeds by conventional analysis and had no unusual transonic Mach number effects.

Future Plans: This work is complete.

Figure 42(a).

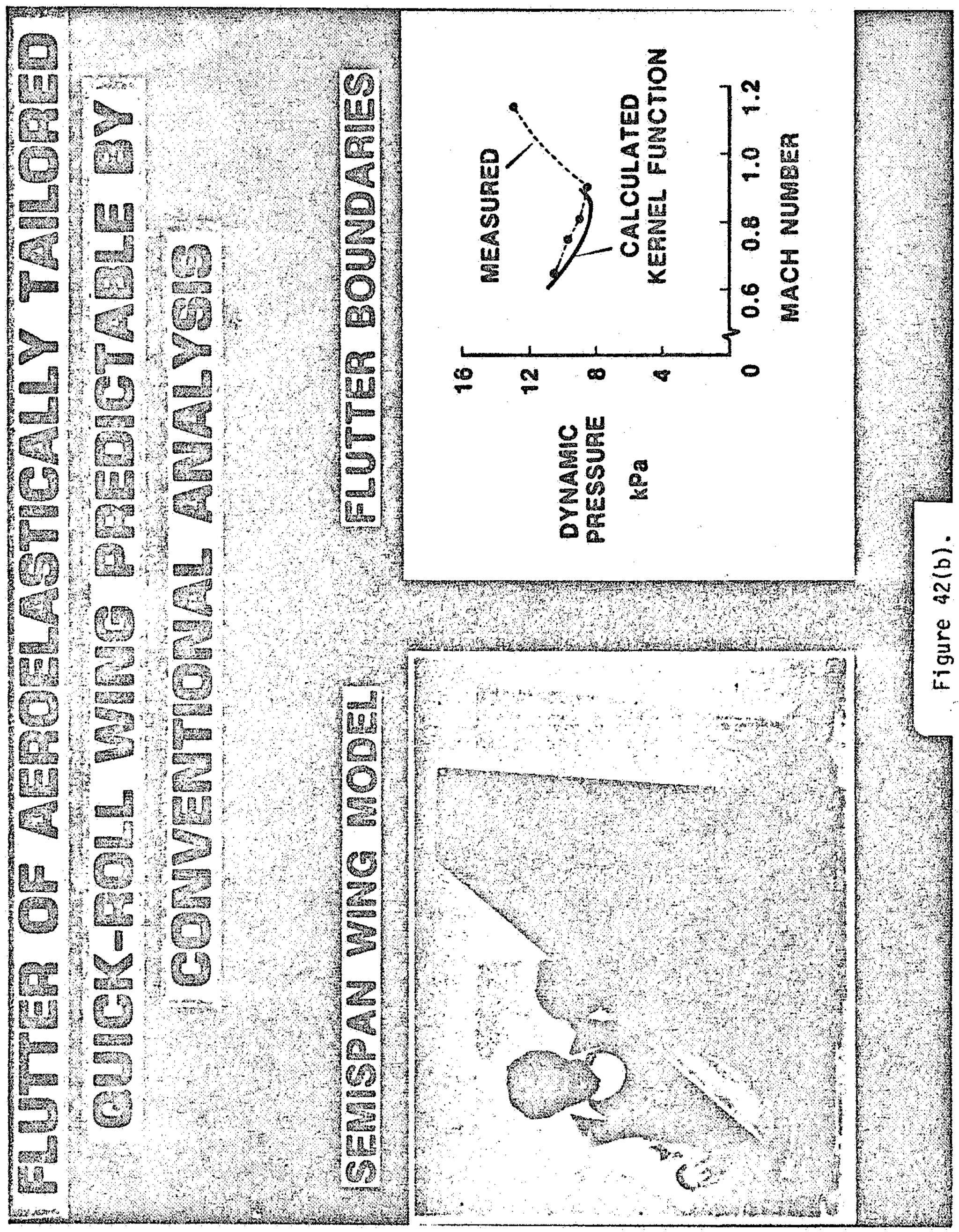

FLUTTER OF AEROELASTICALLY TAILORED
QUICK-ROLL WING PREDICTABLE BY
CONVENTIONAL ANALYSIS
SEMISPAN WING MODEL
FLUTTER BOUNDARIES
DYNAMIC
PRESSURE
kPa
16
12
8
4
0
0.6
0.8
1.0
1.2
MACH NUMBER
MEASURED
CALCULATED
KERNEL FUNCTION

Figure 42(b).

SUPERCRITICAL AIRFOIL LOWERS TRANSONIC FLUTTER BOUNDARY
OF LARGE TRANSPORT WING WITH ENGINES

F. W. Cazier, Jr.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-33-53

Research Objective

To evaluate the flutter characteristics of a supercritical wing in comparison with a wing of the same planform but having a conventional airfoil.

Approach

A 1/12 scale half-span model of a large transport wing with two pylon mounted engines and a half-body fairing is shown in the figure. Two airfoil configurations were tested: one a design with a conventional airfoil that has been in service for about 15 years and the other an advanced supercritical airfoil that is being developed for a future transport. The model is of a sectionalized construction wherein a metal spar provided the wing stiffness characteristics and balsa wood/fiberglass shells fitted over the spar to provide proper aerodynamic shape. The same spar and mass distribution was used for both wing models and the structural modes were very similar. Both wings had identical planform geometry and the same pylon mounted engines. Thus the differences in the flutter characteristics are attributable solely to the airfoil shape. The maximum thickness to chord ratio for the conventional wing was 11% whereas it was 14% for the supercritical wing.

The models were sidewall mounted in the Transonic Dynamics Tunnel. All tests were conducted in Freon. Mach number was increased at constant total pressure until either the model fluttered or a Mach number of 0.9, which was the maximum Mach number for this configuration, was reached.

Accomplishment Description

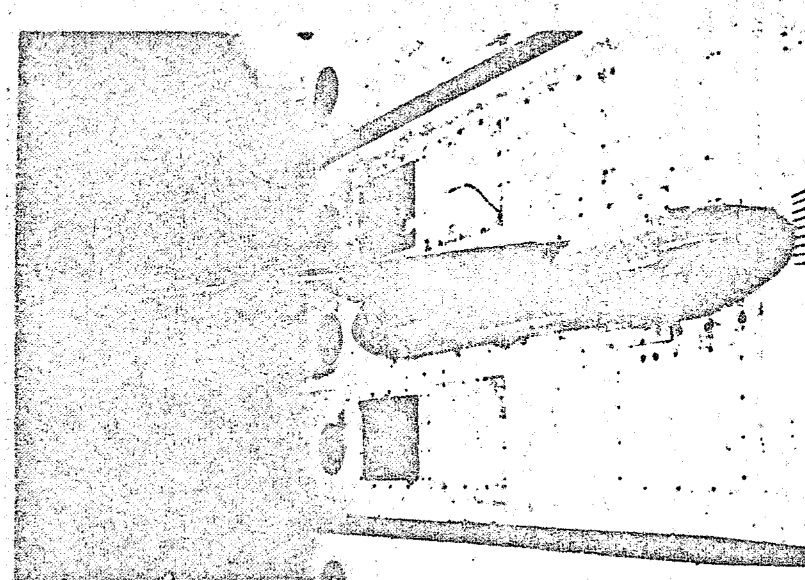
The flutter boundary for each of the models is shown in the right-hand side of the figure. Each of the models exhibits a transonic dip in the flutter boundary. Throughout the speed range the supercritical wing has lower flutter velocities than the wing with a conventional airfoil. The reductions in flutter dynamic pressure varied from 9% up to 40%. Whereas some of the reduction in the flutter boundary could be attributed to the increase in thickness of the supercritical wing, the majority is due to the airfoil shape.

Future Plans

The model was instrumented at two sections with 8 unsteady pressure transducers located in the surface, and 39 pressure ports connected to 4 scani-valves at each section. The static and unsteady pressure data acquired during the test are being analyzed. This data may provide insight into the reasons for the differences in the flutter characteristics of the two airfoils.

Figure 43(a).

SUPERCRITICAL AIRFOIL LOWERS TRANSONIC FLUTTER BOUNDARY OF LARGE TRANSPORT WING WITH ENGINES



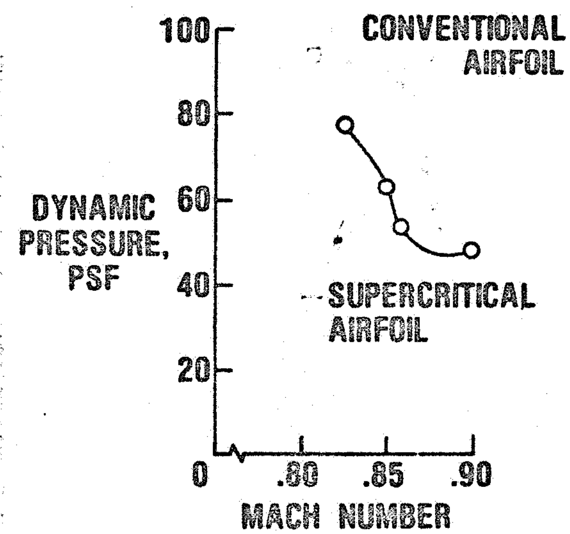


Figure 43(b).

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EVALUATION OF FOUR SUBCRITICAL RESPONSE METHODS FOR ON-LINE PREDICTION OF FLUTTER ONSET IN WIND-TUNNEL TESTS

Charles L. Ruhlin, Judith J. Watson, and Rodney H. Ricketts
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-33-53

Research Objective

Flutter tests in wind tunnels are conducted to define the flutter characteristics of models of complete aircraft or their components. Such testing necessarily entails the risk of model damage due to the destructive oscillations that can occur at flutter. This risk is reduced if the flutter onset can be predicted from the model behavior in the subcritical region below the flutter boundary. To accomplish this, the vibration modes critical to flutter must be identified and the damping and frequencies of these modes measured and tracked as the test conditions are varied until a damping trend can be reliably extrapolated to a flutter condition of zero damping.

Approach

Wind-tunnel model studies using a model representative of an advanced fighter airplane were conducted in the Transonic Dynamics Tunnel to evaluate four subcritical response (SR) methods for on-line use during wind-tunnel tests where the model is excited solely by airstream turbulence. Schematic illustrations of each technique (Peak-Hold, Cross-Spectrum, Power-Spectral Density, and Randomdec) are shown in the figure.

Accomplishment Description

The illustrative results shown in the figure were obtained at Mach number 0.82. For this case all four SR methods provided flutter-mode damping trends from which the flutter-onset dynamic pressure could be reliably predicted. This is clearly seen by comparing each predicted flutter dynamic pressure (q_p) with the actual experimental flutter dynamic pressure ($q_{f,exp}$). Although there are advantages and disadvantages to each technique, the Peak-Hold and Cross-Spectrum methods appear to be the best suited for on-line, near real-time use because they provide damping trends more easily and readily than the other two methods.

Future Plans

This work is part of a continuing effort to develop improved subcritical response methods for use in both wind-tunnel and flight flutter tests.

Figure 44(a).

FOUR SUBCRITICAL RESPONSE METHODS EVALUATED FOR ON - LINE PREDICTION OF FLUTTER ONSET IN WIND TUNNEL TESTS

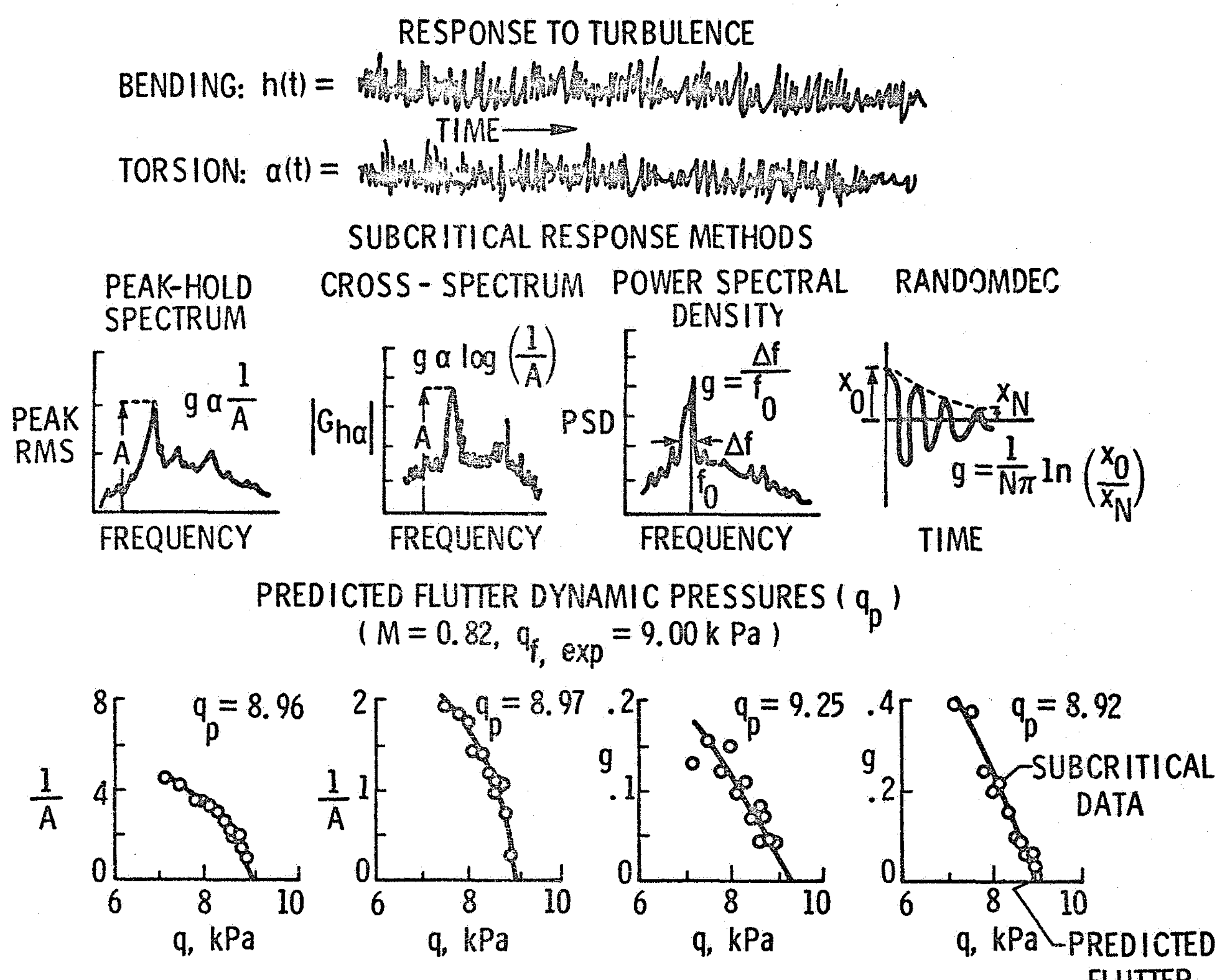

Figure 44(b).

PARAMETRIC TIP EFFECTS DETERMINED FOR CONFORMABLE ROTOR APPLICATIONS

W. R. Mantay and W. T. Yeager, Jr.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-42-13

Research Objective

Reducing helicopter vibratory loads while improving performance is the goal of the Aeroelastically Conformable Rotor (ACR) concept. The current ACR design methodology incorporates reduced blade torsional stiffness and planform geometry to achieve its goals. To obtain maximum benefits from the ACR concept, it is important that the effects of geometry changes on loads and performance be determined.

Approach

Wind tunnel tests of a model rotor representing a modern utility class helicopter were conducted using the Aeroelastic Rotor Experimental System (ARES) in the Langley Transonic Dynamics Tunnel to parametrically evaluate seven blade tip designs. The tips incorporated a systematic variation in geometric parameters such as sweep, taper, and anhedral to evaluate the effect of these parameters, and combinations thereof, on blade torsional response, rotor performance, and vibratory loads. Each rotor configuration was tested at scaled flight conditions representative of the utility class helicopter. Flight parameters of interest included advance ratio μ, rotor tip Mach number M_T, and blade loading coefficient C_L/σ.

Accomplishment Description

As the data shown in the figure illustrate, changes in tip geometry produced marked variations in rotor performance and vibratory loads. Incorporation of sweep, taper, and anhedral in rotor tip geometry significantly reduced vibratory loading and power required as compared to a conventional tip shape. Sweep and taper without anhedral also improved loads and performance. This systematic determination of key parametric effects provides important data for future conformable rotor development.

Future Plans

Results of this research will be published in a series of reports, formal NASA publications and conference papers. The results will be integrated into an Army ATL-sponsored program to develop an ACR optimized for low vibrations and performance.

Figure 45(a).

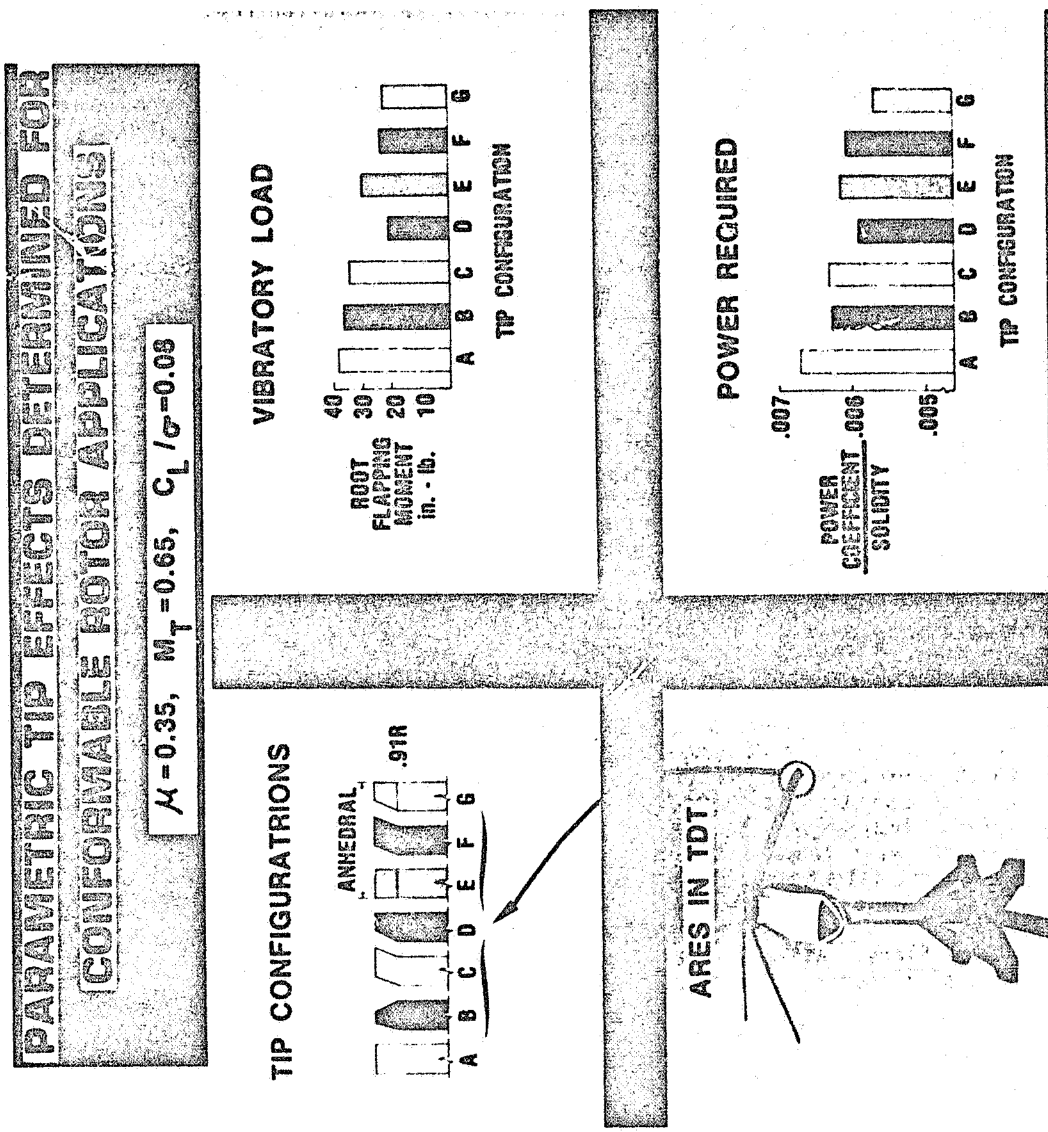
PARAMETRIC TIP EFFECTS DETERMINED FOR
CONFORMABLE ROTOR APPLICATIONS
μ=0.35, M_T=0.65, C_L/σ=0.08
TIP CONFIGURATRIONS
ANHEDRAL
.91R
A B C D E F G
ARES IN TDT
VIBRATORY LOAD
ROOT FLAPPING MOMENT in. - lb.
40
30
20
10
A B C D E F G
TIP CONFIGURATION
POWER REQUIRED
POWER COEFFICIENT / SOLIDITY
.007
.006
.005
A B C D E F G
TIP CONFIGURATION

Figure 45(b).

FLIGHT TEST OF MANUALLY OPERATED HIGHER HARMONIC CONTROL SYSTEM COMPLETE

John H. Cline
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-42-23

Research Objective: The goal of the Higher Harmonic Control (HHC) vibration reduction system is the elimination of helicopter fuselage vibrations that occur at the helicopter blade passage frequency. The current NASA/U.S. Army/Hughes Helicopter, Inc. flight tests of HHC are to validate the success in vibration reduction achieved in TDT and to assess factors that cannot be studied properly in the wind-tunnel tests. These factors are such things as system power consumption, rotor noise, and reaction of the system to maneuvers.

Approach: Higher harmonic control is achieved by superimposing non-rotating swashplate motions at the blade passage frequency (4P for a 4 bladed rotor) upon the basic collective and cyclic flight control inputs. This is accomplished by sensing the vibrations with accelerometers and feeding the accelerometer signals back through a digital computer programmed with a self-adaptive optimal control law. Command signals output by the computer are routed to hydraulic actuators attached to the swashplate. The amplitude and phase of these signals is such that the swashplate and in turn the rotor blades are driven to minimize the vibrations. To install the HHC system on the Army OH-6 helicopter, several modifications had to be made to the helicopter control system. First, three high frequency hydraulic actuators had to be inserted in place of conventional control linkages. Second, some mechanical linkages in the control system had to be modified to add the additional stiffness required to transmit the HHC actuation forces. Finally, a flight-worthy computer and other special electronics equipment were installed.

Accomplishment Description: Prior to conducting closed-loop (computer engaged) tests it is necessary to conduct "open-loop" tests (amplitude and phase of command signals set manually). To date, the HHC-equipped helicopter has undergone over 30 hours of ground and flight tests. These manual tests, which exercised all components of the HHC system with the exception of the digital computer and the adaptive control law, have been completed for flight speeds from hover to 100 knots. As the data show, the HHC system substantially reduces the 4P vibration levels. Further, comments from the pilot and flight engineer were very positive, giving Vibration Rating Scale (VSR) ratings about one-half those of the baseline (system off) helicopter.

Future Plans: After completion of the programming of the HHC algorithm on the digital computer, closed-loop flight tests will be conducted. The successful flight tests of the closed-loop HHC system is expected to lead to an Army-funded technology-transfer-demonstration flight test for members of the helicopter industry and other interested personnel. Because the basic research program will then be complete, further development of the HHC concept will probably be transferred to the Army Applied Technology Laboratory (ATL), Ft. Eustis.

Figure 46(a).

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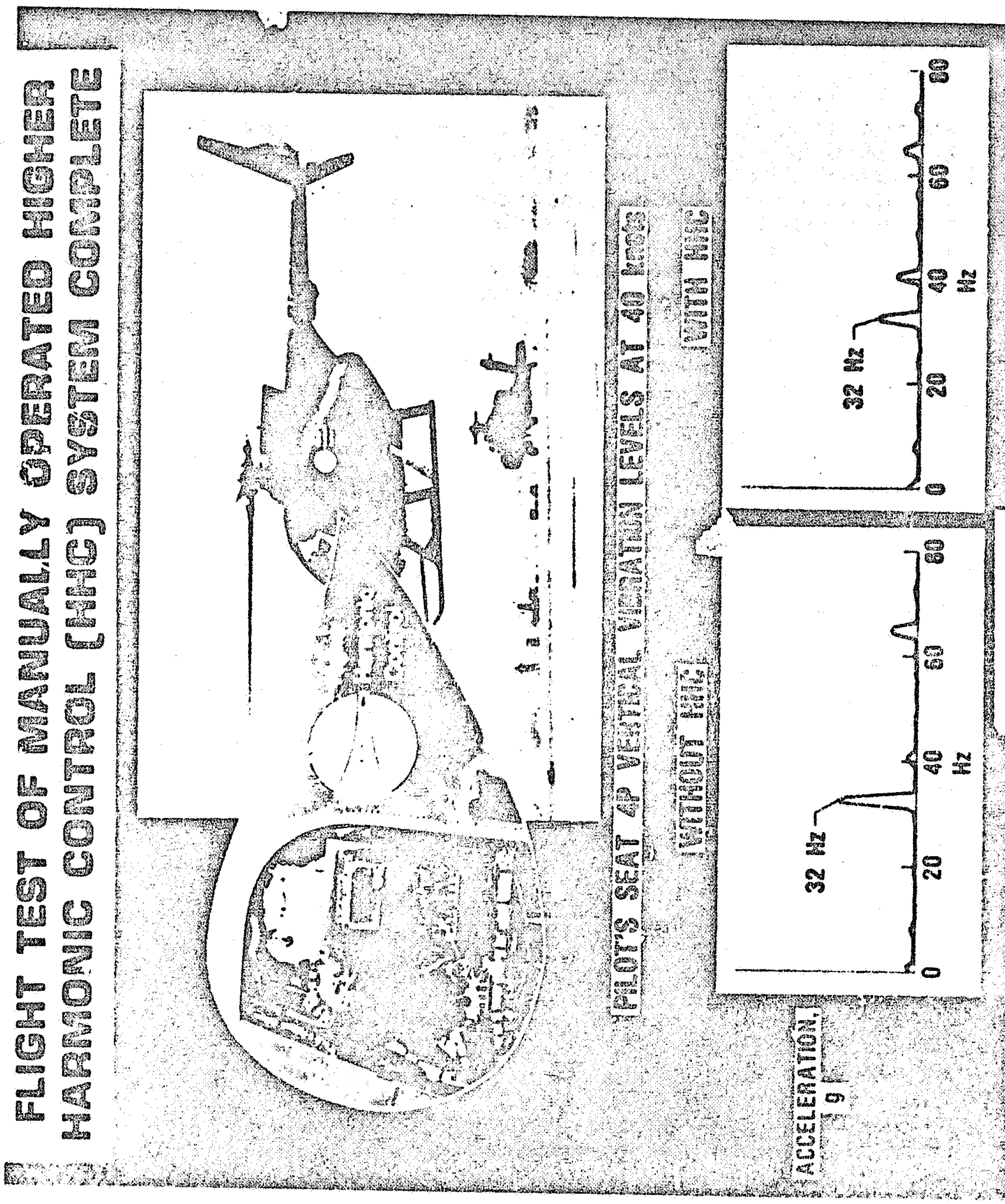

Figure 46(b).

COMPREHENSIVE DESIGN PROCEDURE DEVELOPED FOR PENDULUM VIBRATION ABSORBERS FOR ROTOR BLADES

Warren H. Young, Jr.
Configuration Aeroelasticity Branch
Extension 2661

RTOP 505-42-13

Research Objective: Fuselage vibration problems encountered by Army helicopters have required costly fixes during the prototype flight stage of development. The major source of vibration is the forced response of the fuselage caused by fluctuating rotor airloads and blade dynamics. Therefore, passive absorbers in the rotating system are attractive because they attenuate vibratory hub loads close to the source of the vibrations. One simple passive device is the pendulum absorber mounted under the rotor blade. Pendulum vibration absorbers have been used effectively on aircraft such as the OH-6 helicopter shown in the figure and are attractive for use on future helicopters. If helicopter vibration suppression selection is to move from a post-flight-test fix status to an integral part of the design process the ability to analytically select and assess such devices as the pendulum absorber becomes essential.

Approach: M. Nabil Hamouda and G. Alvin Pierce at the Georgia Institute of Technology (NASA Grant 1592) have developed of a two-step design procedure that allows optimized selection of the absorber parameters and prediction of absorber effectiveness. The first step in the process is the selection of three pendulum parameters: mass, natural frequency, and spanwise location on the blade. The analysis combines the dynamics of the pendulum and a straight, slender, variably twisted, rotating beam which represents the blade. The selection process is made more economical by using a single point harmonic excitation. Comparison to results using unsteady aerodynamic excitation confirmed the adequacy of using single point excitation for selecting the pendulum parameters. The efficiency of the selection process is increased further by selecting the pendulum frequency before analyzing combinations of mass and spanwise location. However, calculation of the spanwise distribution of unsteady airloads is necessary for the second step of the design process which is to the evaluate the effectiveness of the pendulum absorber. The measure of effectiveness is the attenuation of the vibratory forces at the hub. These hub forces were used as a basis for comparing two types of simple pendulum absorbers, lead-lag and flapping.

Accomplishment Description: Some illustrative results are shown in the figure in terms of the effects of pendulum spanwise location and frequency on vertical hub force. This study has produced some useful general design information. For example, the hub forces were found to be little affected by blade precone, but blade twist had a significant effect for both the lead-lag and flapping pendulums. When these analysis techniques are applied to future helicopter designs, the hub forces determined in the second step of the design process will be useful for comparing the simple pendulum absorber to other vibration control devices.

Future Plans: This work is complete.

Figure 47(a).

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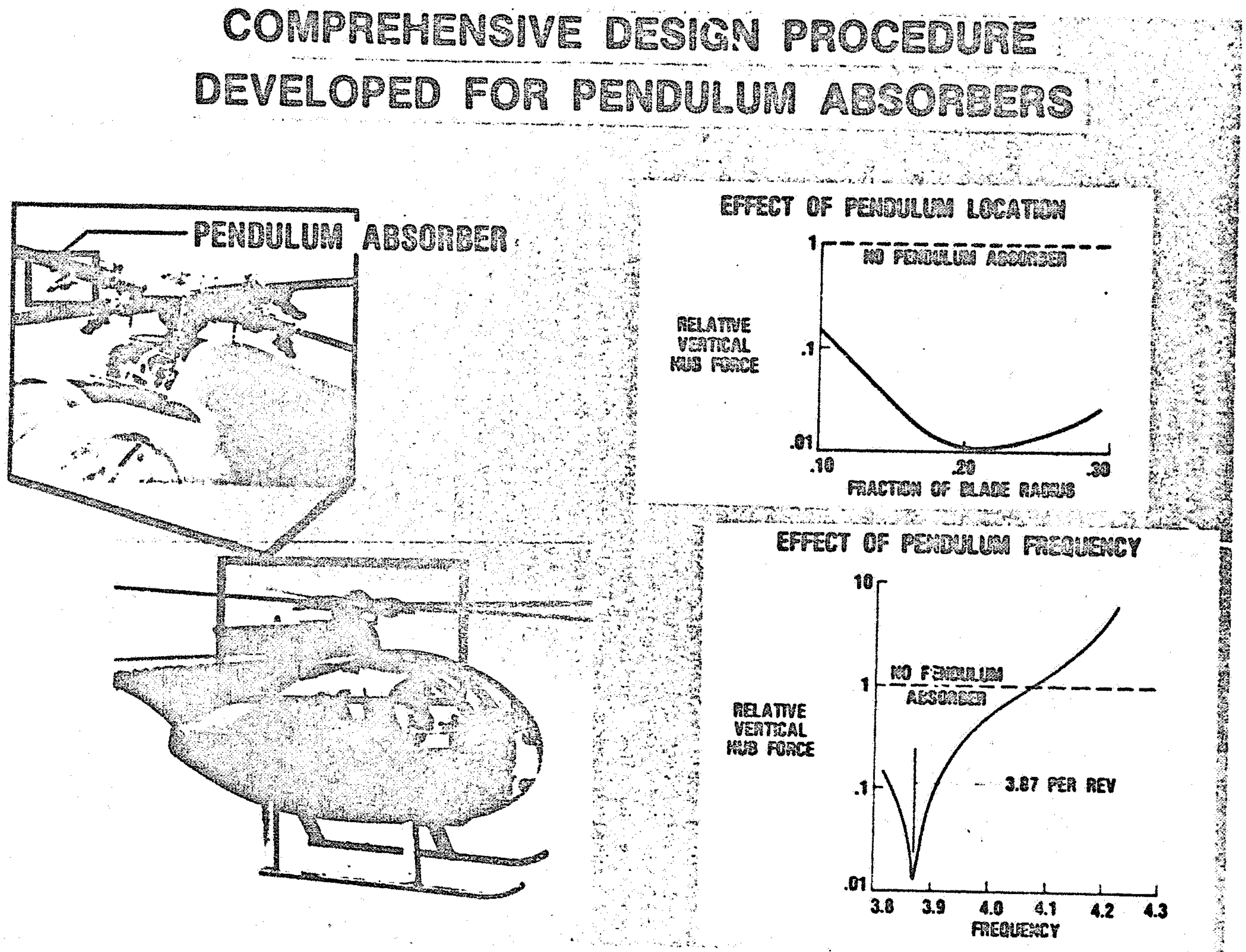

Figure 47(b).

A FORMULATION OF ROTOR-AIRFRAME COUPLING FOR DESIGN ANALYSIS OF VIBRATIONS OF HELICOPTER AIRFRAMES

Raymond G. Kvaternik and William C. Walton, Jr.
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Extension 2661

RTOP 505-42-13

Research Objective

There has been a void in the literature on analysis of vibrations of rotor-airframe systems. Emphasis has been predominantly lain on mathematical modeling of the rotor system with incorporation of the airframe system only casually addressed. The objective is to formulate a procedure for practical vibrations analysis of helicopters which does accord appropriate attention to treatment of the airframe. The main intent is to develop a procedure applicable for analytical support of industrial structural design.

Approach

The rotor is represented by a set of general linear differential equations with periodic coefficients which may be specialized to represent any rotor undergoing small vibrations. Such linear equations describing the rotor can be extracted from all current and expected mathematical models of rotors. The airframe differential equations are as derived from a typical structural analysis by the finite element method which is the accepted tool for structural analysis among U.S airframe manufacturers. Coupling between rotor and airframe is specified through general equations which may be specialized to represent any interface arrangement likely to be encountered. Solution of the resulting differential equations for the coupled rotor-airframe system is effected by a specially developed algorithm based on the harmonic balance method. Considerable computational advantage is realized from this algorithm because the system vibratory responses involve only a limited number of harmonics.

Accomplishment Description

The projected formulation has been developed and is set forth in NASA Reference Publication 1089. (For early domestic dissemination, review for general release June 30, 1984.) This paper provides an adequate theoretical basis and exposition of computational steps for helicopter company structural departments to account for vibrations in design and design studies for the next decade.

Future Plans

This work is complete.

Figure 48(a).

FIRST PUBLISHED GENERAL FORMULATION OF THE HARMONIC BALANCE EQUATIONS OF A COUPLED ROTOR-AIRFRAME SYSTEM

$$\begin{bmatrix} H \end{bmatrix} \begin{Bmatrix} W \end{Bmatrix} = \begin{Bmatrix} P \end{Bmatrix}$$

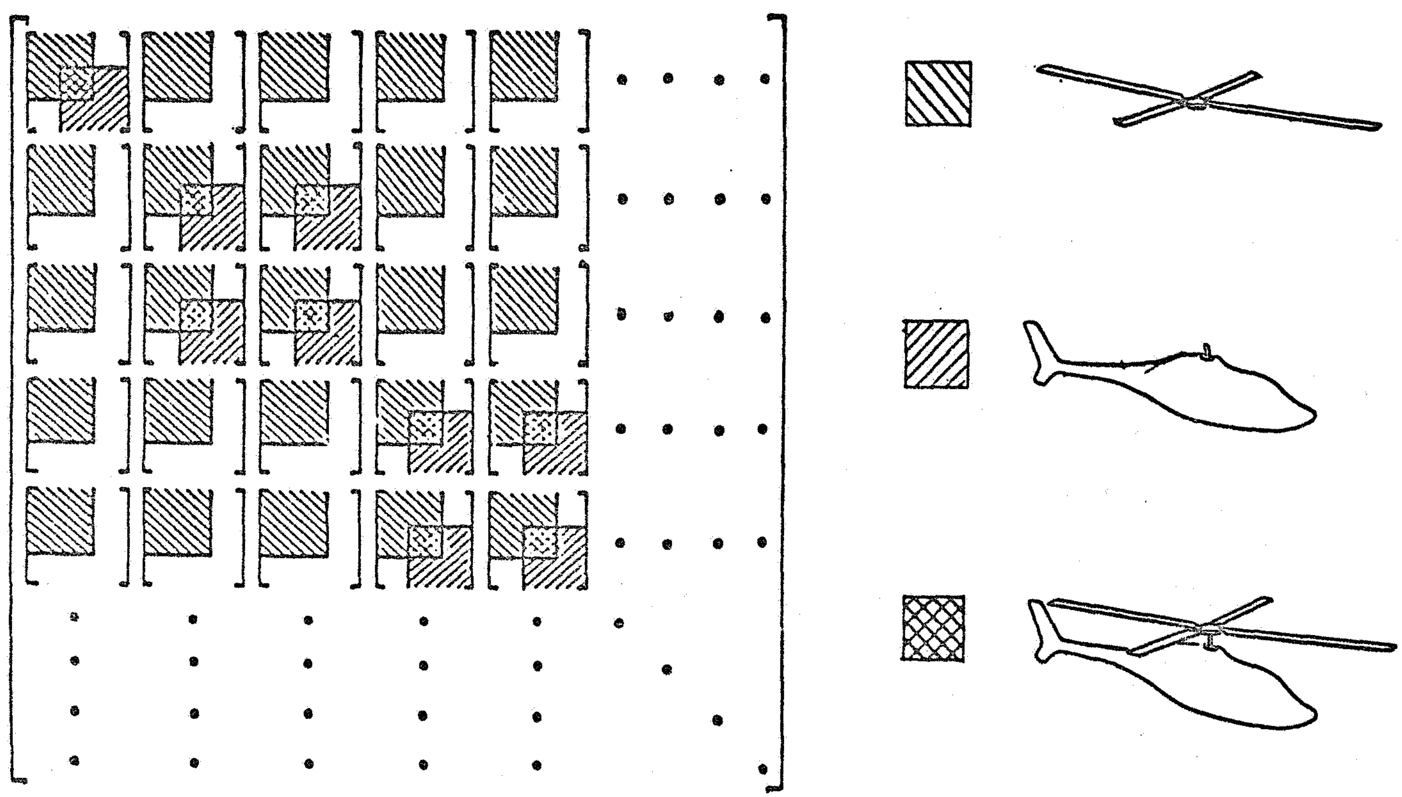

Figure 48(b).

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PLANNING, CREATING AND DOCUMENTING A FINITE ELEMENT VIBRATIONS MODEL OF A HELICOPTER

E. C. Naumann, W. C. Walton, Jr., and R. G. Kvaternik
Configuration Aeroelasticity Branch
Extension 2661

RTOP 532-06-13

Research Objective

Currently, mathematical models based on the finite element method of structural analysis are widely used by the helicopter industry to calculate internal loads and vibrations of airframe systems. These finite element models are the only applicable theoretical prediction technique which affords sufficient representation of structural detail. Advisory groups have indicated a need for NASA to work with the helicopter industry to resolve problems which the industry has been experiencing in efforts to make vibrations predictions using these models. The objective is to establish industry-wide a body of modeling guides which will enable future confident prediction of airframe vibrations within well defined limits of accuracy.

Approach

NASA has sponsored the Boeing Vertol Company to conduct an application of finite element modeling with an emphasis on predicting structural vibrations. The company's production CH-47D helicopter is used as the modeling subject. The following seven steps were specified: (1) Develop guides for forming a finite element model of the subject airframe under the conditions of a design project, giving attention to modeling techniques and, as well, to organization cost and schedule to do the modeling work, (2) Present the modeling guides to the other regular U.S. manufacturers of helicopter airframes for critique, (3) Form a finite element model of the subject airframe according to the understood guidelines, (4) Define requirements for vibration measurements and for correlations of analysis with measurements to evaluate the finite element model, (5) Submit the test requirements to the other companies for critique, (6) Carry out the test correlation program according to the understood requirements, and finally (7) Implement an evaluation of the test-correlation results by the participating companies.

Accomplishment Description

This program has proceeded into Step 6, analysis/test correlation phase. An illustrative example of calculated and measured frequency response functions is shown in the figure. The correlations which have been obtained are considerably improved over similar attempts of the past and should go a long way toward removing uncertainty about the limits of applicability of finite element models for vibrations prediction.

Future Plans

The evaluation of final results by participating companies, Step 7, is scheduled for early 1983. In addition, the correlation will be expanded to include the comparison of existing flight vibration data with the finite element model results.

Figure 49(a).

CH-47D TESTS/NASTRAN ANALYSIS CORRELATION

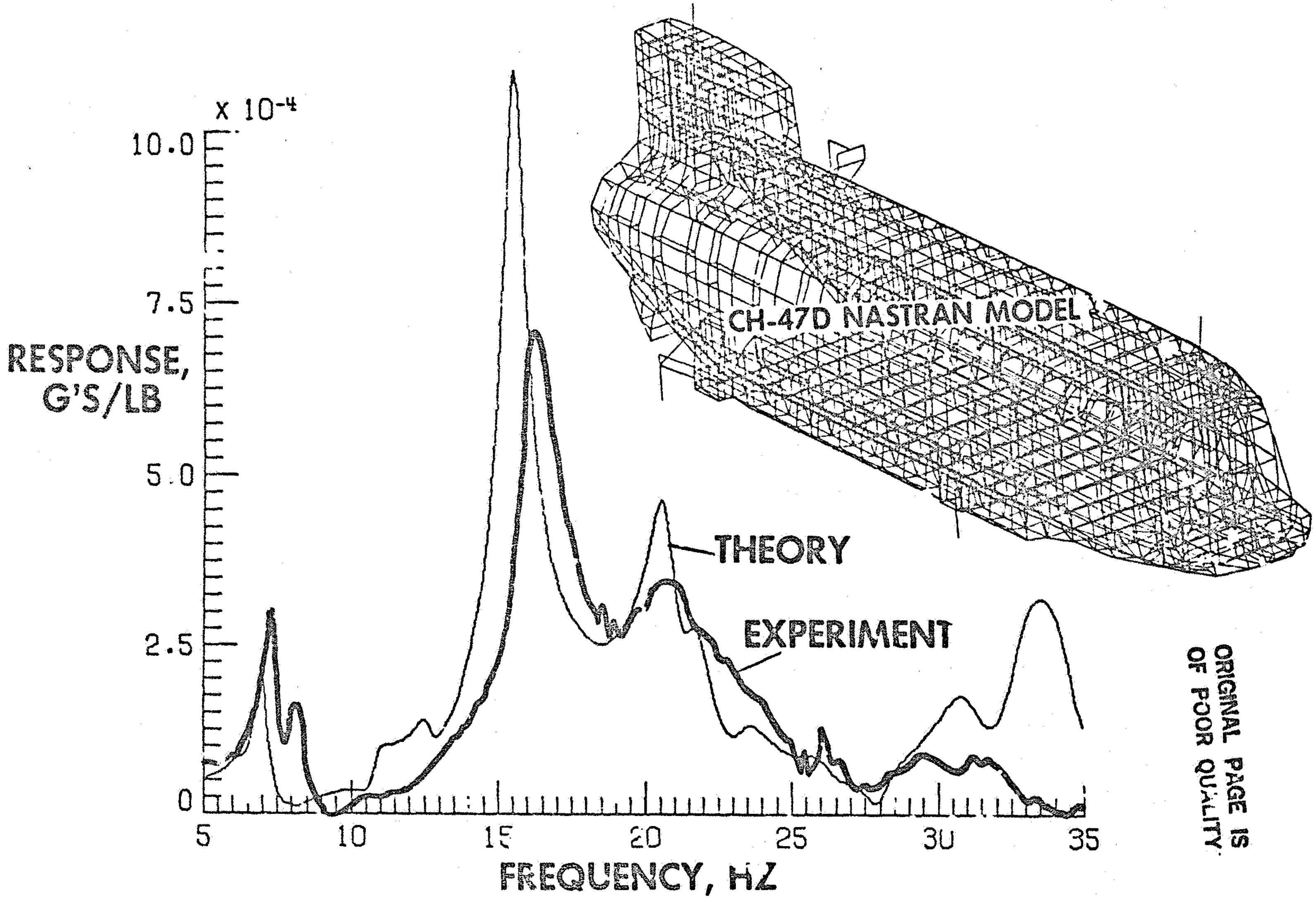

Figure 49(b).

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AEROTHERMAL LOADS

FY 83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
A	506-51-23	DOCUMENT WING-ELEVON COVE HEATING TESTS BY 12/82	EFFECT OF SEPARATED FLOW ON COVE ENVIRONMENT DEFINED	IN TECHNICAL EDITING REVIEW
B	506-51-23	DOCUMENT GAP HEATING RESULTS INCLUDING FLOW ANGULARITY EFFECTS 6/83	FLOW ANGULARITY EFFECTS ON LOCAL AND TOTAL TILE HEATING DEFINED	PUBLISH MS THESIS & 18TH THERMOPHYSICS 6/83
C	506-51-23	INITIATE DESIGN AND FAB OF GENERIC (1) PROTUBERANCE, (2) CHINE GAP HEATING AND (3) 1/3 SCALE ELEVON-ELEVON GAP HEATING MODEL	BASIC MODELS FOR GENERIC AEROTHERMAL RESEARCH IN FY 83-84	(1) CONCEPT DEFINED (2) IN DESIGN (3) DESIGN COMPLETE FAB INITIATED
D	506-51-23	DOCUMENT GAS JET NOSE TIP DATA OBTAINED ON DNA CONICAL MODEL IN 8' HTT BY 2/83	EFFECTIVENESS OF DNA NOSE TIP CONCEPT EVALUATED	LARC DATA REDUCTION COMPLETE, WAITING 12-1/2 CONE AND PDA RESULTS FOR COMPLETION
E	506-51-23	DOCUMENT TEST RESULTS OF 12-1/2° FILM COOLED CONE IN 8' HTT BY 6/83	COOLING EFFECTIVENESS OF TWO CONCEPTS DEFINED	TEST IN PROGRESS - COMPLETE BY 11/83

Figure 50(a).

AEROTHERMAL LOADS

FY 83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
F	506-51-23	DOCUMENT 3D NAVIER STOKES (NS) SOLT. FOR THERMAL BOWED TPS 6/83	EFFECT OF BOWING ON FLOW & HEATING DEFINED, CRITICAL PARAMETERS AND INFLUENCE DEFINED	PARAMETER STUDY UNDERWAY PUBLISH 18TH THERMOPHYSICS 6/83
G	506-51-23	INITIATE EFFORT TO DEVELOP 3D PARABOLIZED NS FLOW FIELD CODE APPLICABLE TO CSTA 3/83	ANALYTICAL VERIFICATION OF TEST RESULTS	-JSC EFFORT STARTED -CONTRACT RFP FOR FD & FE APPROACH BY 11/83
H	506-53-53	DEVELOP 2D ELEMENTS AND VECTORIZATION TECHNIQUES FOR COMPRESSIBLE NS FEM CODE FOR LOCAL DETAILED FLOW-THERMAL-STRUCTURAL ANALYSIS 10/83	INTEGRATED ANALYSIS CAPABILITY	2D CODE BEING EVALUATED
I	506-53-53	DEVELOP 2D FE FOR INTEGRATED THERMAL-STRUCTURAL ANALYSIS OF STS AND ORBITING STRUCTURES 6/83	EXTENSION OF METHODOLOGY TO BROADER PRACTICAL APPLICATIONS	TO BE DEMONSTRATED ON SHUTTLE WING AND ORBITING STRUCTURE

Figure 50(b).

AEROTHERMAL LOADS

FY 83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
J	506-53-53	DEMONSTRATE IMPROVED RADIATION ANALYSIS CAPABILITIES OF CODE DEVELOPED UNDER GRANT TO U OF W 6/83	IMPROVED EFFICIENCY AND ACCURACY	INCORPORATE IN SPAR, APPLY TO SPACE STRUCTURE
K	506-53-53	~~DEMONSTRATE CAPABILITIES OF MIXED IMPLICIT-EXPLICIT ALGORITHM ON A PRACTICAL PROBLEM 9/83~~	EXTENSION TO NONLINEAR PROBLEM	GRANT NOT RENEWED IN FAVOR OF HIGHER PRIORITY PAY OFF EFFORT
L	506-53-53	EXTEND ELEMENT TO ELEMENT ALGORITHM TO ALL HEAT TRANSFER MODES - 9/83	REDUCED COMPUTER RESOURCES/INCREASED MODEL SIZE	ALGORITHM EVALUATION UNDERWAY
M	506-53-33	DOCUMENT STUDY OF STIFFNESS PROPERTIES OF MULTIWALL 12/82	DESIGN CRITERIA FOR MW	REPORT IN REVIEW
N	506-53-33	TEST FLAT ARRAY OF SA TPS PANELS IN 8' HTT 3/83; DOCUMENT RESULTS 9/83	PROVIDE VERIFIED DURABLE TPS FOR 1000°F TO 2000°F RANGE	ARRAY DELIVERED 9/82 TEST SCHEDULED 1/83

Figure 50(c).

AEROTHERMAL LOADS

FY 83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
O	506-53-33	DESIGN OF MODIFIED CSTA TO ACCEPT ARRAY OF CURVED TPS PANELS - 12/82	TEST APPARATUS MODIFIED FOR TPS EVALUATION	DESIGN UNDERWAY BY ROHR
P	506-53-33	DESIGN, FAB, & DELIVERY OF ARRAY OF CURVED SA TPS PANELS 5/83	DEMONSTRATE METALLIC TPS FOR CURVED SURFACES	DESIGN INITIATED TEST FY 84
Q	506-53-33	DESIGN, FAB, & DELIVERY OF ACC TPS INTERSECTION MODEL FOR TESTS AT LARC 12/82	1ST GENERATION ACC PANEL FAB.	ON SCHEDULE PANEL DELIVERY 2/83
R	506-53-33	TEST ACC TPS MODEL IN 20 MW AAT 3/83	1ST GENERATION ACC TPS EVALUATED	TEST PLANNED FOR 3/83
S	505-33-73	COMPLETE EVALUATION OF O_2 ENRICHMENT SYSTEM IN 7" HTT 6/83	DESIGN DETAILS IDENTIFIED FOR PROPOSED 85 CoF	MOD TO TUNNEL STARTED - TEST EARLY CY 83
T	505-33-73	DETERMINE INSERT CONTOUR & FLOW BYPASS REQUIREMENTS, OPERATIONAL RANGE, FLOW QUALITY 9/83	ALTERNATE MACH NO. CONCEPT AND CAPABILITIES DEFINED	INSERTS BEING DESIGNED

Figure 50(d).

AEROTHERMAL LOADS

FY 83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
U	506-53-33	OPERATION AND MAINTENANCE OF AEROTHERMAL LOADS COMPLEX	EFFICIENT, PRODUCTIVE FACILITIES, IMPROVED TEST TECHNIQUES	BEING ACCOMPLISHED
V	506-51-23	DEFINE FLOW FIELD FOR CSTA IN 8' HTT BY 6/83	3D FLOW FIELD DEFINED FOR GENERAL PURPOSE TEST APPARATUS	MODEL IN PREP. FOR TEST 11/82
W	506-51-23	COMPLETE CALIBRATION OF ~~TPSTF~~ 1X3 HEAT FOR HEAT-SINK LINER WITH 20% O_2 6/83	TUNNEL READY FOR WATER COOLED LINER AND HIGH ENTHALPY CALIBRATION	-UNDERWAY -PILOT BURNER LIGHTOFF ACHIEVED
X	506-51-23	INITIATE CALIBRATION OF WATER-COOLED ~~TPSTF~~ 1X3 HEAT LINER - 9/83	TUNNEL READY FOR RESEARCH	LINER TO BE DELIVERED 9/83

Figure 50(e).

METALLIC THERMAL PROTECTION SYSTEMS

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Aerothermal Loads Branch
Extension 3155

RTOP 506-53-33

Research Objective

As a part of the overall research objective to develop durable thermal protection systems for future space transportation systems, two Metallic Thermal Protection Systems (MTPS) have been developed. These two prepackaged systems are the Titanium Multiwall (Ti M/W) and the Superalloy Honeycomb (SA/HC) Thermal Protection Systems (TPS). Arrays of the MTPS will be subjected to multiple cycles of both radiant and aerothermal heating representative of space transportation system entry conditions to evaluate the aerothermal performance and structural integrity of the metallic tiles.

Approach

The two 20 MTPS tile (17.5 square feet) arrays shown were fabricated for radiant and aerothermal heating tests in the 8' High Temperature Tunnel (HTT). These tests will demonstrate the thermal performance of the concepts and will determine the capability of the overlapping joints to prevent the flow of hot gases in the space between the tiles. A two panel array of each concept will undergo thermal vacuum tests at the Johnson Space Center, Building 13, radiant heating/vacuum test facility to evaluate their thermal performance in the entry condition. In addition to the array tests, single panel tests will be conducted for the following environments: vibration, acoustics, water retention, foreign object damage, and lightning strike damage.

Future Plans

The arrays of flat panels and the separate single panels have been delivered and are being prepared for testing in mid FY 83. An array of curved SA/HC panels for testing in the 8' HTT are being fabricated for delivery in late FY 84.

Figure 51 (a).

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METALLIC TPS ARRAYS FOR 8-FT HTST TESTS

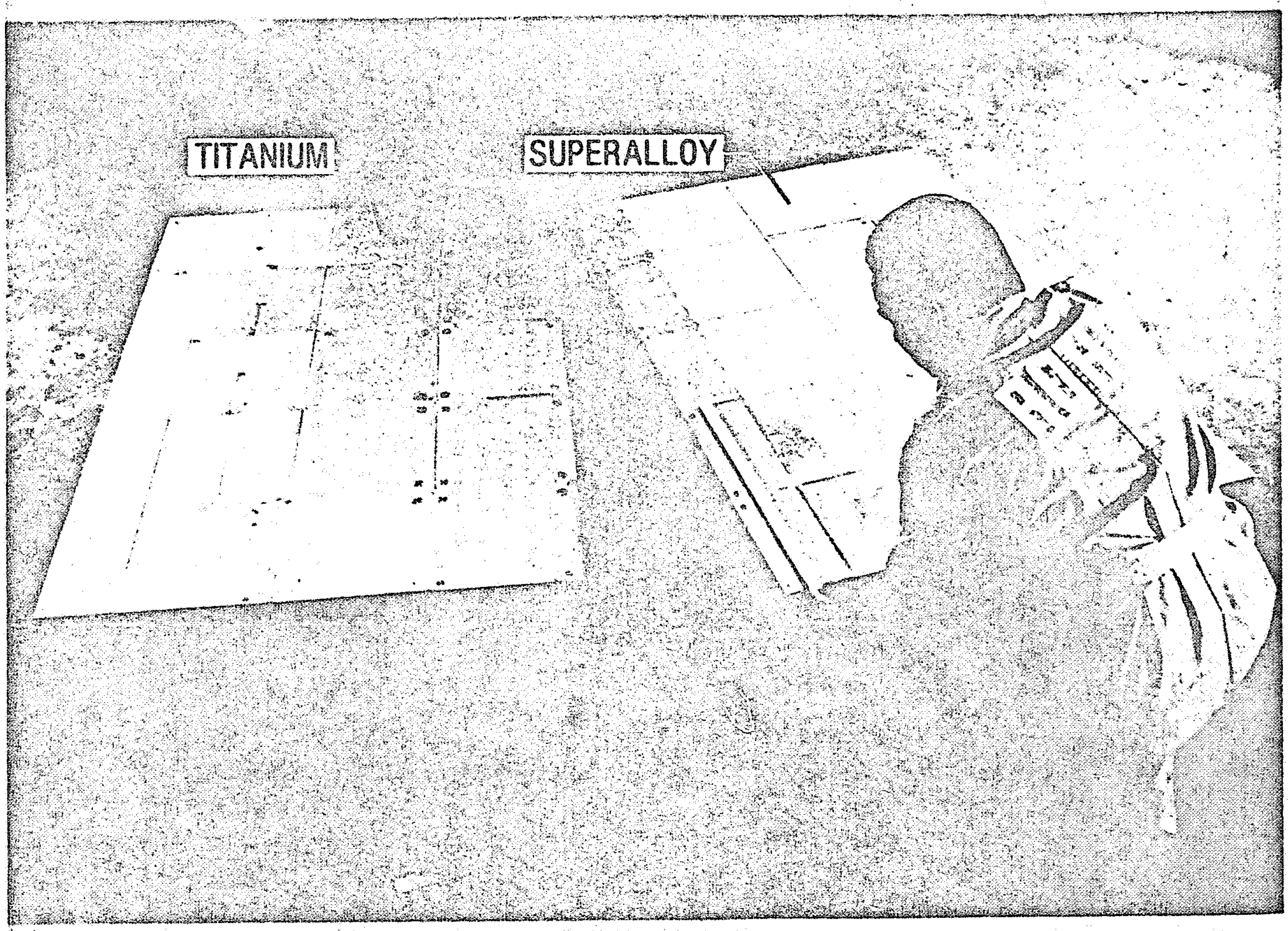


Figure 51(b).

ADVANCED CARBON-CARBON HEAT SHIELD RESEARCH

Claud M. Pittman
Aerothermal Loads Branch
Extension 3155

RTOP 506-53-33

Research Objective

One of the most promising durable TPS concepts for application to the highly heated areas of Future Space Transportation Systems is advanced carbon-carbon (ACC). This material is a derivative of the reinforced carbon-carbon (RCC) material which is being used successfully on the Shuttle nose-cap and wing leading-edges. The RCC material has been modified to improve strength and oxidation resistance and renamed ACC. The ACC TPS concept consists of large overlapping ACC panels (approximately 3 ft. x 3 ft.) mounted on post supports with packaged fibrous insulation between the ACC panels and the main vehicle structure. The objective of this research is to develop high temperature durable TPS systems.

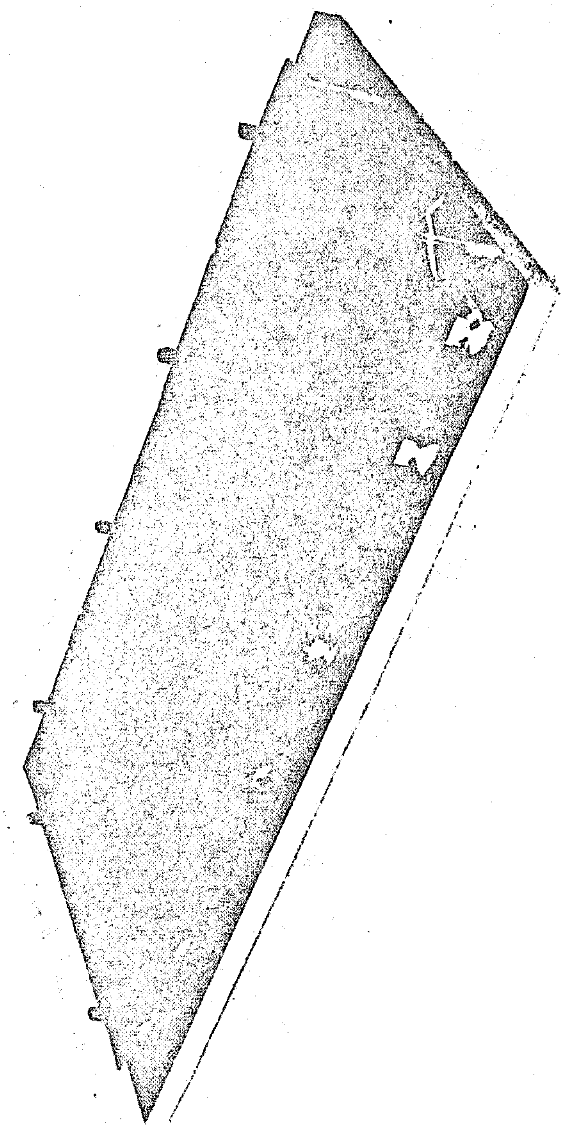
Approach

The ACC test article is shown in the attached figure. The test article is composed of four panel segments, representing the intersection of four ACC multipost concept panels. The overall size of the test article is 1 ft by 2 ft and the height can be adjusted to permit testing different TPS thicknesses and insulation packages. The test article will be delivered complete with ACC panels and seals, support posts, packaged insulation, simulated vehicle structure and appropriate thermocouple instrumentation. The test article will be tested in both radiant heating and arc-tunnel environments. Testing in these two environments should provide a good measure of the thermal efficiency of the heat shield and a comparison of the performance between the two environments should indicate whether hot gas flow through the panel joints is significant. Any weight change in the ACC panels due to high temperature exposure can also be determined.

Future Plans

Fabrication of the ACC test article is nearly complete and should be tested in early 1983. The next step in this research will be to obtain a large panel array for testing in the 8-Foot High Temperature Tunnel. This array will incorporate design modifications gleaned from the ACC tunnel and foreign object damage tests. Data from these tests will more clearly define the thermal and structural response of the ACC heat shield concept.

Figure 52(a).



ACC ARC-TUNNEL TEST ARTICLE DURING FABRICATION

MASS ADDITION FILM COOLING TESTS OF A 12.5 DEGREE CONE
IN THE LANGLEY EIGHT-FOOT HIGH TEMPERATURE TUNNEL

Robert J. Nowak
Aerothermal Loads Branch
Extension 3115

RTOP 506-51-23

Research Objective

Mass addition film cooling--injection of a fluid into the stagnation region or the surface boundary layer--is an attractive method of providing thermal protection from hostile aerodynamic heating. Film cooling is an active system that could benefit space transportation vehicles by supplementing the passive thermal protection systems in local areas experiencing excessive heat loads. Also, the nose tips of high velocity missiles operating at low altitude require additional cooling to survive. Many experimental and analytical studies have been conducted on film cooling; however, very little experimental data exist for tests in high enthalpy hypersonic flow. Therefore, a test program was designed for the Langley 8-Foot HTT to study the cooling effectiveness of both forward facing and tangential coolant ejection.

Approach

The cooling effectiveness tests were planned using a large 12.5 degree cone with a base diameter of 3 feet. The cone model has various nose tips for the different ejection methods and solid nose tips to obtain base line data with no coolant ejection. Flow visualization methods are used to describe the coolant interaction with the test stream at the nose, and retractable probes on the cone are used to define the flow field Mach number and temperature distributions with and without coolant ejection. Limited boundary layer gas analysis should help define the ratio of coolant to test stream composition at the cone surface.

Accomplishment Description

A number of tests have been successfully completed including tests at various test conditions and model angles of attack for nose tips with and without coolant ejection. Preliminary results indicate a substantial reduction in cold-wall heating with coolant flow extending far downstream from the ejection port. Excellent flow visualization including shadowgraph and Schlieren coverage reveals the complex process of coolant mixing with the test stream. Also, the gas analysis system was successful.

Future Plans

Analysis of the experimental results is continuing; several documents are anticipated in late CY 83 and early CY 84.

Figure 53(a).

MASS ADDITION FILM COOLING OF A 12.5° CONE
AT MACH 6.8

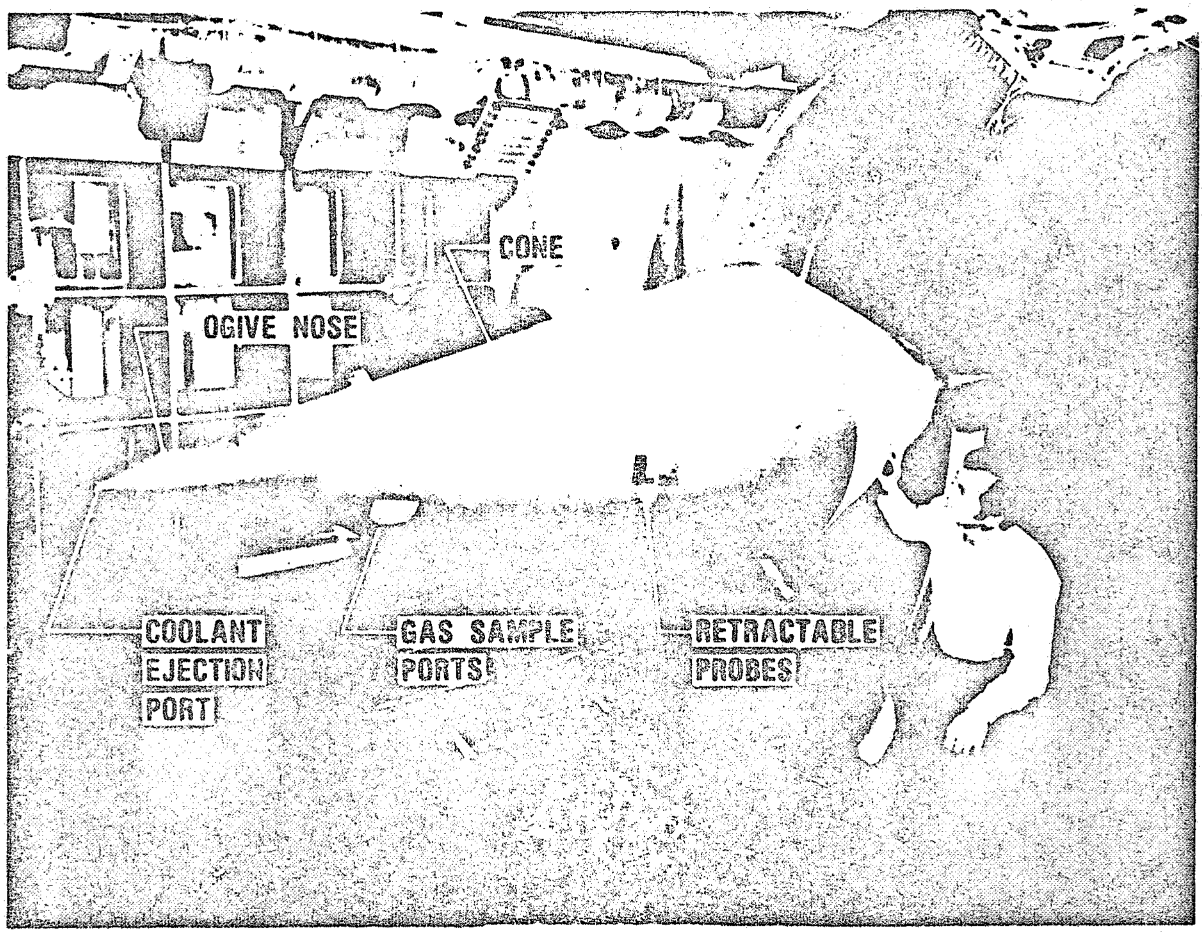


Figure 53(b).

AERODYNAMIC HEATING AND PRESSURE DISTRIBUTIONS ON A BLUNTED THREE-DIMENSIONAL NONAXISYMMETRIC BODY AT MACH 6.8

Cindy W. Albertson
Aerothermal Loads Branch
Extension 2325

RTOP 506-51-23-03

Research Objective

Previous aerothermal testing in the Langley 8-Foct High Temperature Tunnel (8' HTT) of surface thermal-structural concepts for future space transportation vehicles has been limited to two-dimensional and axisymmetric flow fields. To extend test capabilities to three-dimensional flow fields, a general purpose test apparatus representative of the forward portion of a lifting body was developed. This apparatus, referred to as the Curved Surface Test Apparatus (CSTA), will be used for aerothermal studies and thermal-structural testing in the 8' HTT. The present investigation was undertaken to experimentally and theoretically design the aerodynamic heating and pressure distributions on the apparatus in laminar and turbulent boundary layers.

Approach

As shown in the top and side views in the attached figure, the CSTA is 8.9 feet long and 3.0 by 2.0 inches at the base. The nose of the apparatus is spherical with a 3.0 inch radius. A cross section taken towards the aft portion of the apparatus reveals a strong back inner support structure which attaches to the 0.38 inch nickel outer area surface through a series of stand-off assemblies which allow the model to expand thermally. The apparatus is hinged at the base so that it can be opened for access to instrumentation located in the interior. A depth of approximately a .0 in. exists between the strongback and the aero surface to allow access to instrumentation attached directly to the aero surface. This space is also adequate to accept typical TPS concepts while holding the outer line constant.

Future Plans

Wind tunnel tests, currently scheduled to begin in January 1983, will be conducted at a nominal Mach number of 6.8 for angles of attack ranging from -15 to 15° and total temperatures of 2500 R and 3300 R. These tests will be conducted primarily to determine local aerodynamic pressures and heating rate distributions on the surface of the apparatus. A limited amount of information of the flow field away from the surface, in terms of Mach number distributions, will also be obtained. These results will be compared with theoretical predictions which were obtained using a series of computer codes which compute the inviscid flow-field first and then compute the laminar and turbulent boundary layer flow.

Figure 54(a).

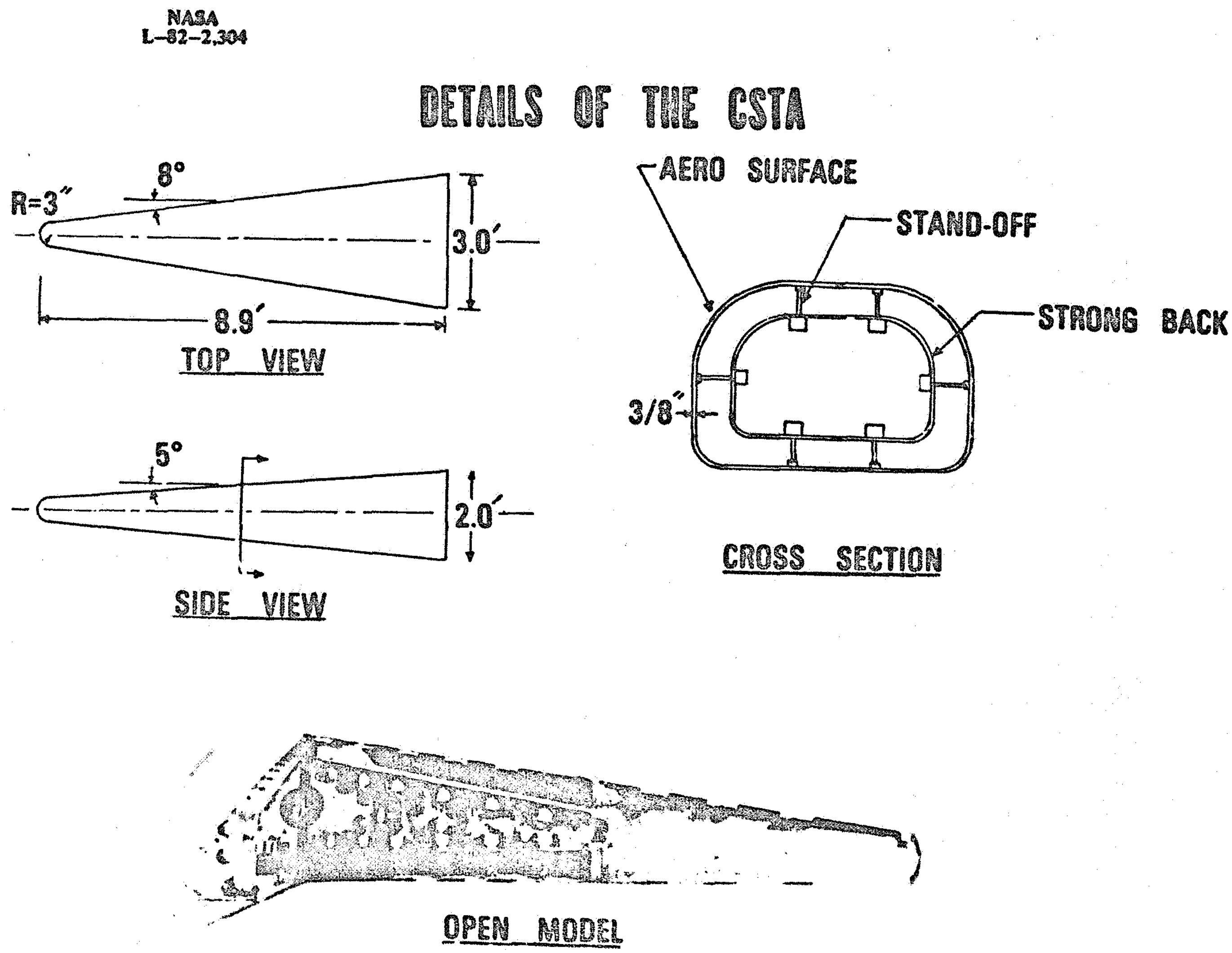

NASA
L-82-2,304
DETAILS OF THE CSTA
R=3"
8°
3.0'
8.9'
TOP VIEW
5°
2.0'
SIDE VIEW
AERO SURFACE
STAND-OFF
STRONG BACK
3/8"
CROSS SECTION
OPEN MODEL

Figure 54(b).

GENERAL PURPOSE TEST APPARATUS FOR 8' HTT

Carl R. Pearson
John R. Karns
Aerothermal Loads Branch
Extensions 3423 and 2154

RTOP 506-53-33

Research Objective

A two dimensional sled has served many years as the "work horse" fixture to mount surfaces for testing in the 8' HTT. It has served very well but current research direction requires the investigation of three dimensional surfaces.

Approach

To meet this need, two additional general purpose test fixtures have been designed.

Accomplishment Description

The Curved Surface Test Apparatus (CSTA), which is representative of the forward portion of a lifting body, will permit evaluation of aerothermal loading around the chine area and permit the verification of curved TPS in an area of large pressure and heating gradients. The basic apparatus, with a "boiler plate" skin in place of a research surface, will be tested in early 1983. Wings, which will be added to the CSTA, are currently under fabrication.

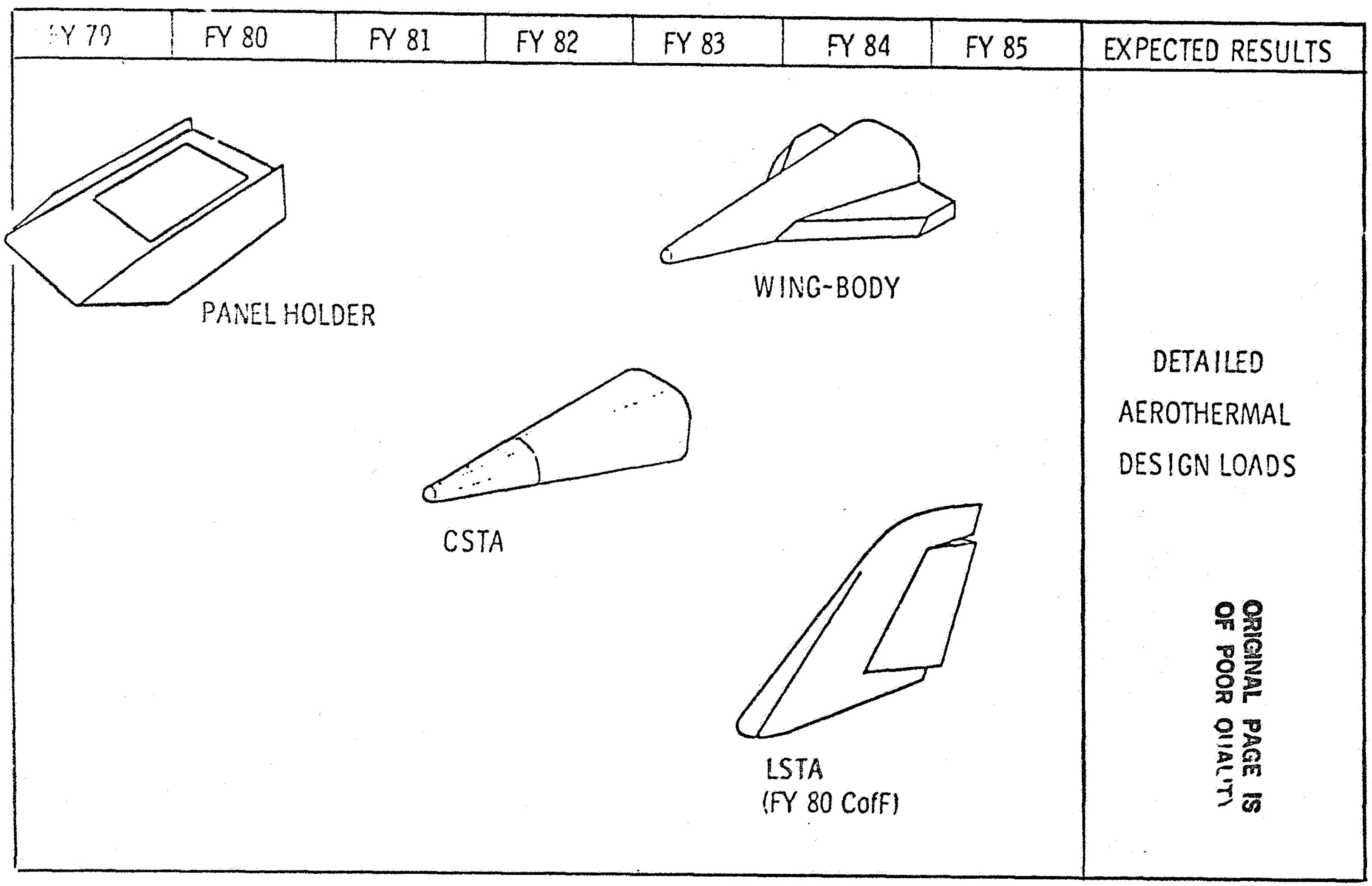
The Lifting Surface Test Apparatus (LSTA) was designed and is being constructed as part of an 80 CofF project. It is a wing with a movable elevon which can be used to mount research surfaces at various locations.

Future Plans

The CSTA is scheduled for calibration in FY 83 and for testing of curved thermal protection panels in FY 84. The LSTA is scheduled for completion in FY 83.

Figure 55(a).

GENERAL TEST APPARATUS



INTEGRATED FLUID-THERMAL-STRUCTURAL ANALYSIS

Allan R. Wieting
Aerothermal Loads Branch
Extension 3423

RTOP 506-53-53

Research Objective

The research objective is to formulate the methodology for analysis of high speed vehicles and large space structures. The methodology will incorporate the basic needs of fluid, thermal, and structural disciplines into a unified approach for analysis of structures whose performance is closely linked to its environment.

Approach

Finite element techniques are generally applied in structural analysis. Consequently finite element thermal analysis techniques have been developed for general heat transfer analyses. Recently, integrated thermal structural techniques have been developed and demonstrated in both one and two dimensions for generic space transportation systems and large space structures applications. These applications demonstrated the potential of integrated finite element methodology, hence, finite element fluid methodology will be investigated. The initial investigations will focus on the evaluation of various finite element techniques and algorithms for both incompressible and compressible flow. This effort is focused primarily on aerodynamic heating and thermal structural performance of future space transportation systems. The thermal structural effort will be extended to large space structures.

Future Plans

During 1983, two and three dimensional finite elements and vectorization techniques for a compressible Navier-Stokes code will be developed. Also, a parabolized Navier Stokes (PNS) solution will be developed to analyze the aerothermal flow field for a wind tunnel model. These analytical results will be compared with experiment and finite difference PNS results. In addition, specialized elements for the thermal structural analysis of large space structures will be developed.

Figure 56.

OXYGEN ENRICHMENT AND ALTERNATE MACH NUMBER CAPABILITY FOR THE 8' HTT

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John R. Karns
Aerothermal Loads Branch
Extensions 3423 and 2154

RTOP 505-33-53

Research Objective

Under a proposed FY 85 construction of facilities project the 8' HTT will be uprated to provided a unique national facility for the testing of air-breathing propulsion systems for hypersonic aircraft and missiles. The required modifications will include an oxygen enrichment system to increase the oxygen content in the test stream to 20% (presently the 8' HTT burns methane in air to produce the high energy flow stream representative of hypersonic flight and uses the oxygen depleted products of combustion as a test medium) and interchangeable nozzles to provide additional (lower) Mach numbers. Anticipated operating characteristics of the modified facility are shown in figure b. The oxygen enrichment system, shown in figure c, will use a nitrogen pressurized, high pressure oxygen supply to inject liquid oxygen directly into the combustor. The alternate Mach number modification, shown schematically in figure d, will use a mixer concept to add additional cool air to the stream and interchangeable nozzle inserts to provide the temperature and pressure required to simulate the lower Mach numbers and altitudes. The basic mixer concept has been demonstrated at AEDC and in the LaRC scramjet facility; however, design details of the alternate Mach number and the oxygen enrichment modifications for this particular application are required.

Approach

Alternate Mach number and oxygen enrichment systems similar to those proposed for the 8' HTT will be tested in the 7" HTT which is a pilot tunnel for the 8' HTT. The 7" tests will be used to evaluate the detailed control requirements for the larger system and to resolve operational problems which can be solved much easier on a small scale. The experience gained by this effort will allow the control scheme to be fine tuned and result in an improved design for the larger system.

Future Plans

The equipment is being designed and installed in the 7" HTT. Testing should be completed by the end of FY 83.

Figure 57(a).

COMPARISON OF OPERATIONAL ENVELOPES FOR LARC'S 8-FOOT HIGH-TEMPERATURE TUNNEL (8-FT HTT) AND AEDC PROPULSION FACILITIES ASTF AND APTU

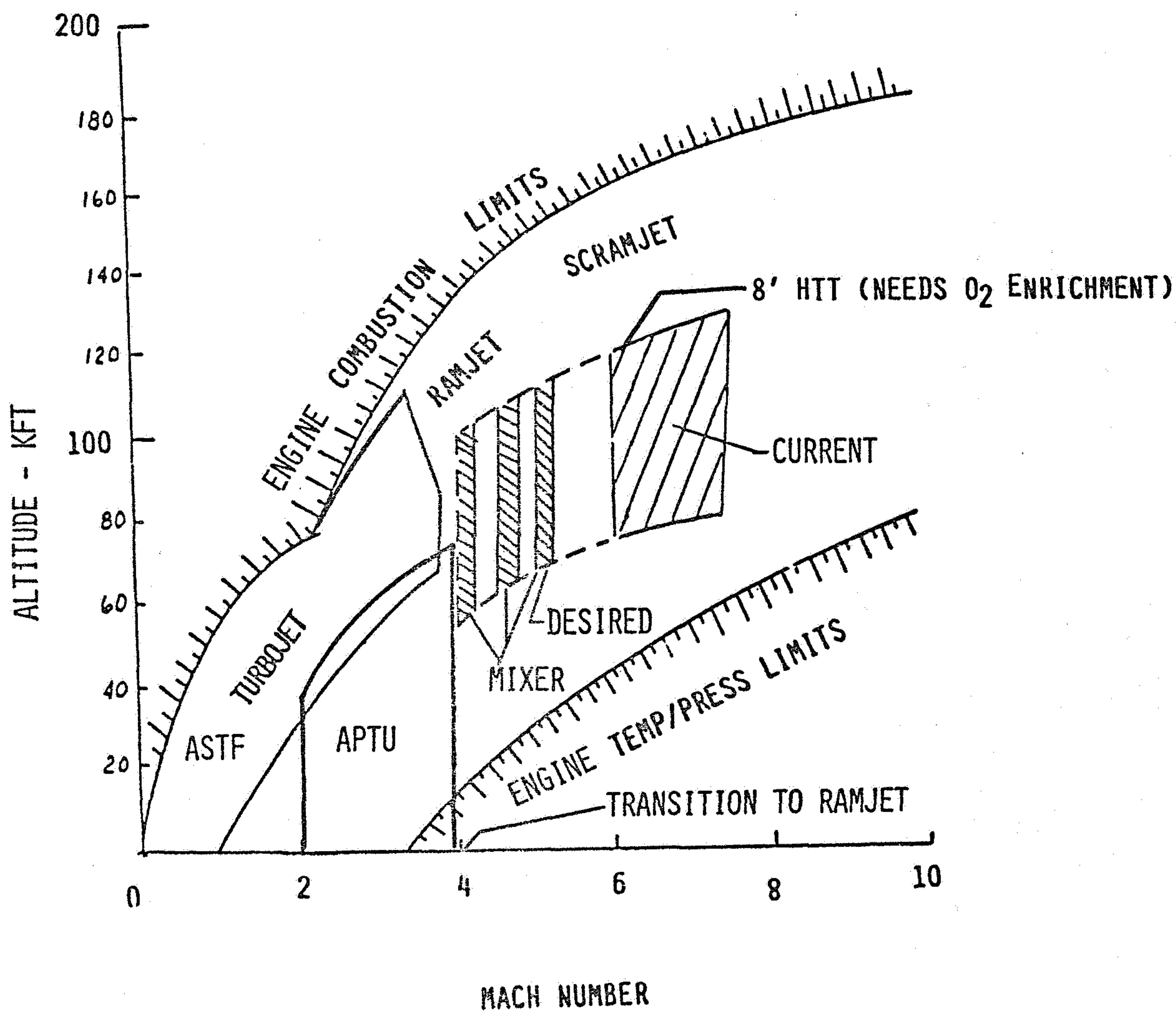

Figure 57(b).

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MODIFICATIONS OF THE 8-FOOT HIGH TEMPERATURE TUNNEL (1265)

EXCESS AFRPL EQUIPMENT TO BE USED FOR LaRC's 8-FOOT HTT OXYGEN ENRICHMENT SYSTEM

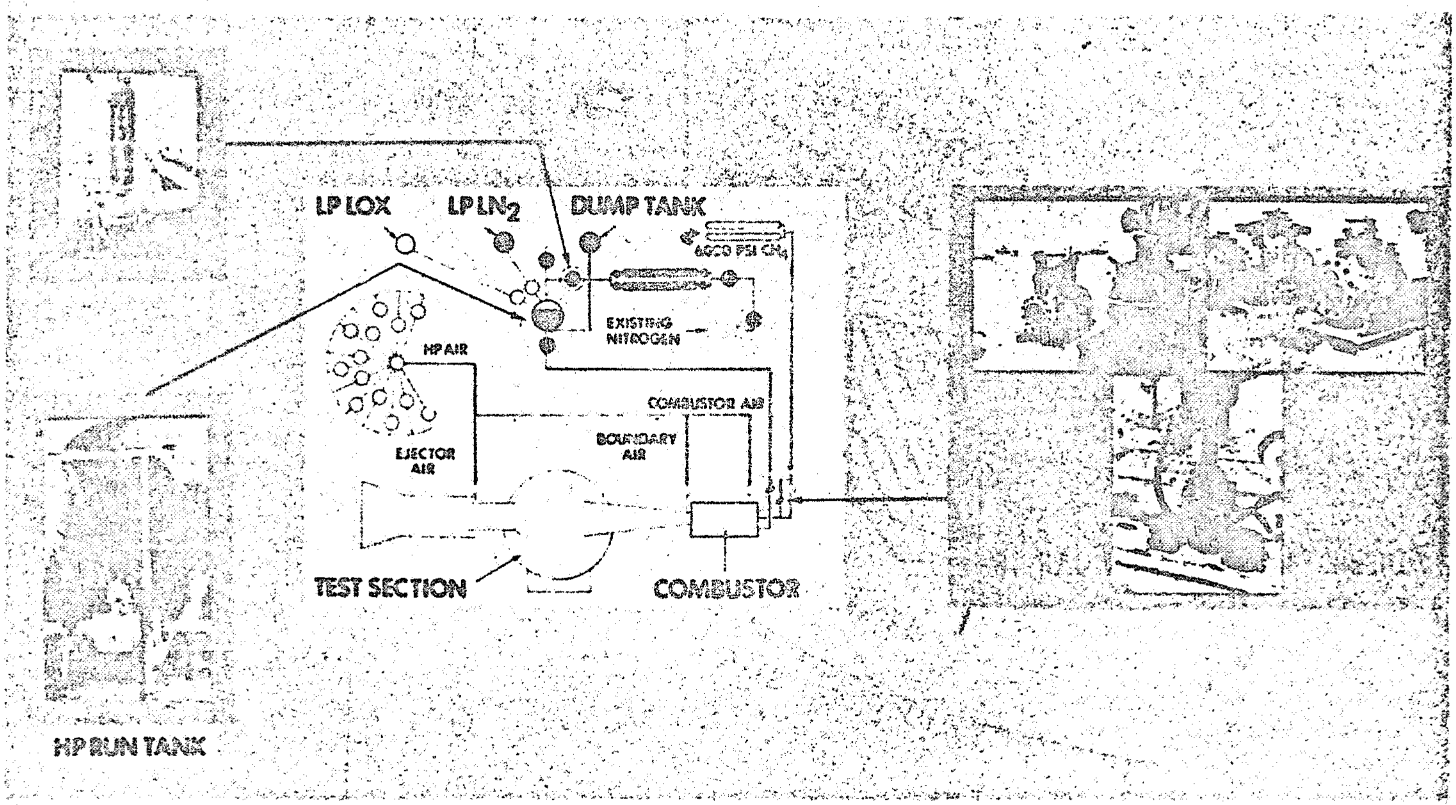

Figure 57(c).

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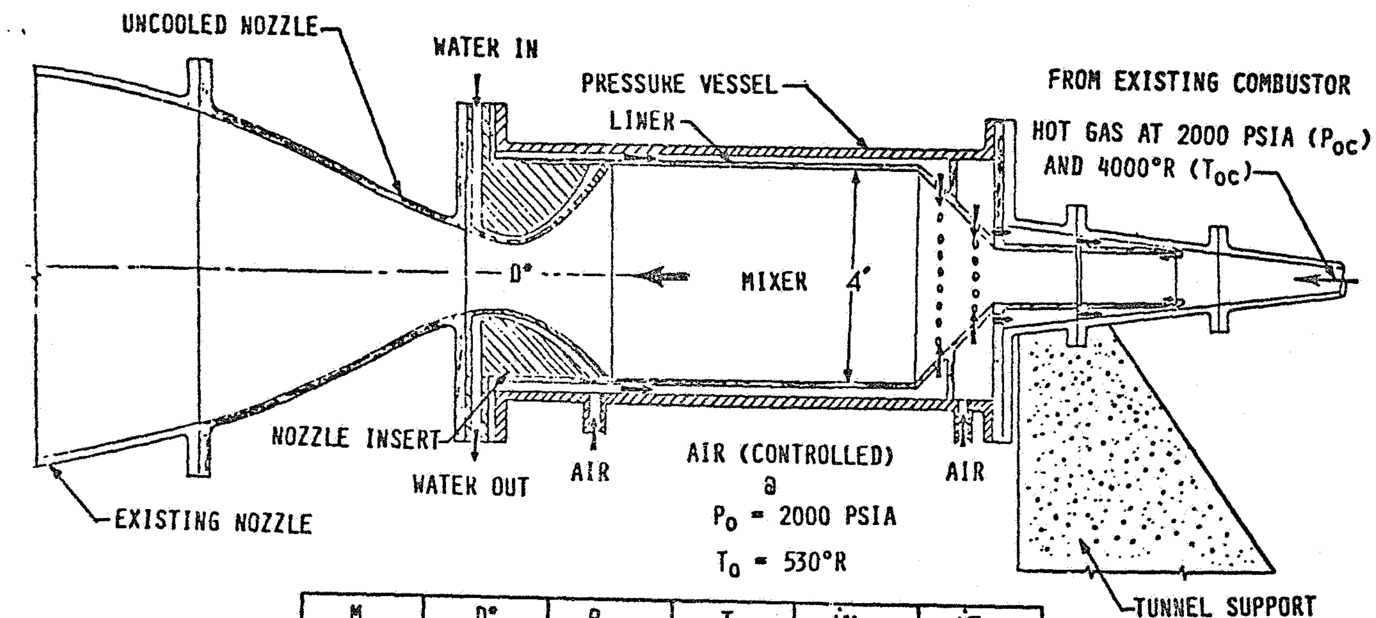
ALTERNATE MACH NUMBER

MIXER CONCEPT



M	D*	P_{ON}	T_O	$\dot{W}M$	$\dot{W}T$
	IN.	PSIA	°R	LB/S	LB/S
4	28.5	234	1640	1436	1927
4.5	22.2	316	1970	933	1424
5.0	17.1	444	2350	597	1088

Figure 57(d).

MULTIDISCIPLINARY ANALYSIS AND OPTIMIZATION

FY'83 MILESTONES/PLANS

NO.	RTOP MILESTONES/PLANS	SIGNIFICANCE	STATUS
	505-33-53		
A	Linearized version of a multilevel optimization tested in a structural application (10/82).	Reduction of the computational cost of optimization.	On schedule.
B	Multilevel optimization method tested in a multidisciplinary application (12/82).	First multidisciplinary demonstration of a unified optimization.	On schedule, merged with a sailplane test case, Ph.D, VPI.
C	First phase (analysis) of the fuel efficient wing optimization task (Lockheed) completed (2/83).	Preparation for an industrial scale demonstration of optimization by decomposition.	On schedule.
D	Advanced modular optimization program implemented at LaRC (4/83).	A large selection of optimization techniques available to the LaRC users.	On schedule.
E	Multilevel optimization procedure defined for the fuel efficient (Lockheed) wing task	Preparation for an industrial scale demonstration of optimization by decomposition	On schedule.
F	Develop a new technique for efficient calculation of derivatives with respect to structural shape variables (7/83).	A radical improvement of computational efficiency in structural shape optimization.	On schedule.
G	One pass through the structural part of the optimization procedure for Lockheed aircraft complete (9/83).	First industrial scale demonstration of optimization by decomposition - - a step toward the unified optimization goal.	On schedule.

Figure 58(a).

FY'83 MILESTONES/PLANS

NO.	RTOP MILESTONES/PLANS	SIGNIFICANCE	STATUS
	506-53-53		
H	Modify orbiter wing structural FEM to reflect the wingtip fin design (12/82).	The FEM will be a basis for numerous structural analysis to be performed in future in support of the new wingtip fin design.	Preliminary version complete
I	Develop thermal finite-element model of Space Shuttle Orbiter (4/83).	As above.	On schedule.
J	Complete implementation of optimum sensitivity analysis in ACCESS 3 (5/83).	Enhancement of an advanced computer code for optimization.	On schedule.
K	Integrate in ISSYS computer programs unique to Space Shuttle Orbiter (6/83).	Developing analysis capability to support the wingtip fin design.	Work suspended to concentrate on H above. Will remain on schedule.
L	Develop a technique for optimization of structures under dynamic loads in a disjoint design space (9/83).	Search for effective, now nonexistent, tool for a large-scale, dynamic structure optimization.	On schedule.
M	Demonstrate critical times technique (3/83).	Needed to predict time of occurrence of peak combined loads.	Method has been identified. Testing initiated.
N	Install radiation view factor analysis in SPAR (4/83).	Will enhance the integrated thermal structural capability of SPAR.	On schedule. Initial phase of installation begun.
O	Initiate grant for heat-pipe analysis methods (11/82).	Needed for analysis and design of heat pipes for space station and STS applications.	Canceled due to lack of FY'83 funds.

Figure 58(b).

FY'83 MILESTONES/PLANS

NO.	RTOP MILESTONES/PLANS	SIGNIFICANCE	STATUS
P	Implement techniques to control thermal deformation and deformation of spacecraft (6/83).	Will provide analytical formulation for controlling thermal distortion of sensitive components in space.	Contract with Perkin-Elmer has been negotiated.
	505-33-53		
Q	Define influence of canards, structural flexibility, and aerodynamic interference on FSW stability (12/82).	Identify major contributing factors to FSW instabilities.	On schedule.
R	Compare state-of-art calculated unsteady aerodynamics due to oscillating controls with measured values (1/83).	Applicability of state-of-art unsteady aerodynamics in the design of active control systems.	Subsonic comparison complete.
S	Establish criteria for robustness of multiloop active control systems (8/83).	Multiloop stability margins included in control law design.	On schedule.
T	In-house synthesis methodology applications to DAST ARW-2 active control system design (9/83).	Application of in-house methods to flight hardware.	On schedule.
	505-33-43		
U	Evaluate FSS to above system-off boundary (ARW-1R) (12/82).	Initial flight evaluation of new FSS.	Problems identified in 11/3/82 flight. Schedule delayed. Est. April flt. to go above boundary.
V	Complete FSS evaluation (4/83).	Data for comparison with prediction	Delayed - Expect to complete, July 83; Cutoff for B-52.

Figure 58(c).

FY'83 MILESTONES/PLANS

NO.	RTOP MILESTONES/PLANS	SIGNIFICANCE	STATUS
W	Complete flight loads tests (ARW-1R) (7/83).	Loads data on flexible SCW to define wing characteristics and evaluate structural model.	Plan to acquire loads data on FSS flights.
	534-02-13 (OGL)		
X	Wing semispan-center section instrumentation complete (1/83).	Wing and auxiliary system buildup complete.	On schedule.
Y	Instrumentation checkouts complete (3/83).	Wing ready for wind-tunnel test.	On schedule.
Z	Wind-tunnel test right semispan complete (6/83).	Obtain unsteady pressure measurements on flexible wing.	On schedule.
AA	Deliver wing to DFRF (7/83)	Ready to begin buildup and checks with flight vehicle.	Wing on schedule. DFRF vehicle systems behind sch.
	505-45-23 (was 505-44-23)		
AB	Longitudinal measurement system installation on B-57B complete (1/83).	Capable of improved longitudinal component measurements.	Install system at DFRF in Jan. 1983.
AC	Flight samplings completed (7/83).	Data available for analyses.	On schedule.

Figure 58(d).

DAST ARW-2 GUST LOADS ANALYSIS

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Extension 3323

RTOP 505-33-43

Research Objective

DAST ARW-2, the second research wing for the drone test bed, will incorporate multiple active control systems including flutter suppression, maneuver load control, gust load alleviation, and relaxed static stability. The overall objective of this research is to evaluate the analysis and synthesis methods used to design multiple-purpose, integrated active control systems. The purpose of the subject analysis is to evaluate the effect of the gust load alleviation control system on gust loads throughout the flight envelope.

Approach

The gust load alleviation (GLA) and relaxed static stability (RSS) systems have been designed under contract (Boeing Wichita) and are indicated schematically on the accompanying figure. The GLA system uses an outboard aileron on the wing and the all-movable horizontal tail to control loads. Since the RSS and GLA systems operate in the same frequency range, it is necessary to evaluate gust loads with both systems active. LaRC is presently evaluating the active control system performance by in-house analysis using the DYLOFLEX system of computer programs. Results of this analysis at many points in the flight envelope will be used to evaluate the contractor's design and to provide data for comparison with flight measurements.

Status/Plans

Modeling of the active control system and the airplane equations of motion have recently been completed. Initial checks of the performance of the system at the GLA design point have been performed and indicate a good comparison with contractor results. It is anticipated that the gust loads analysis will be completed during the first quarter of CY 1983.

Figure 59(a).

DAST ARW-2 GUST LOADS ANALYSIS

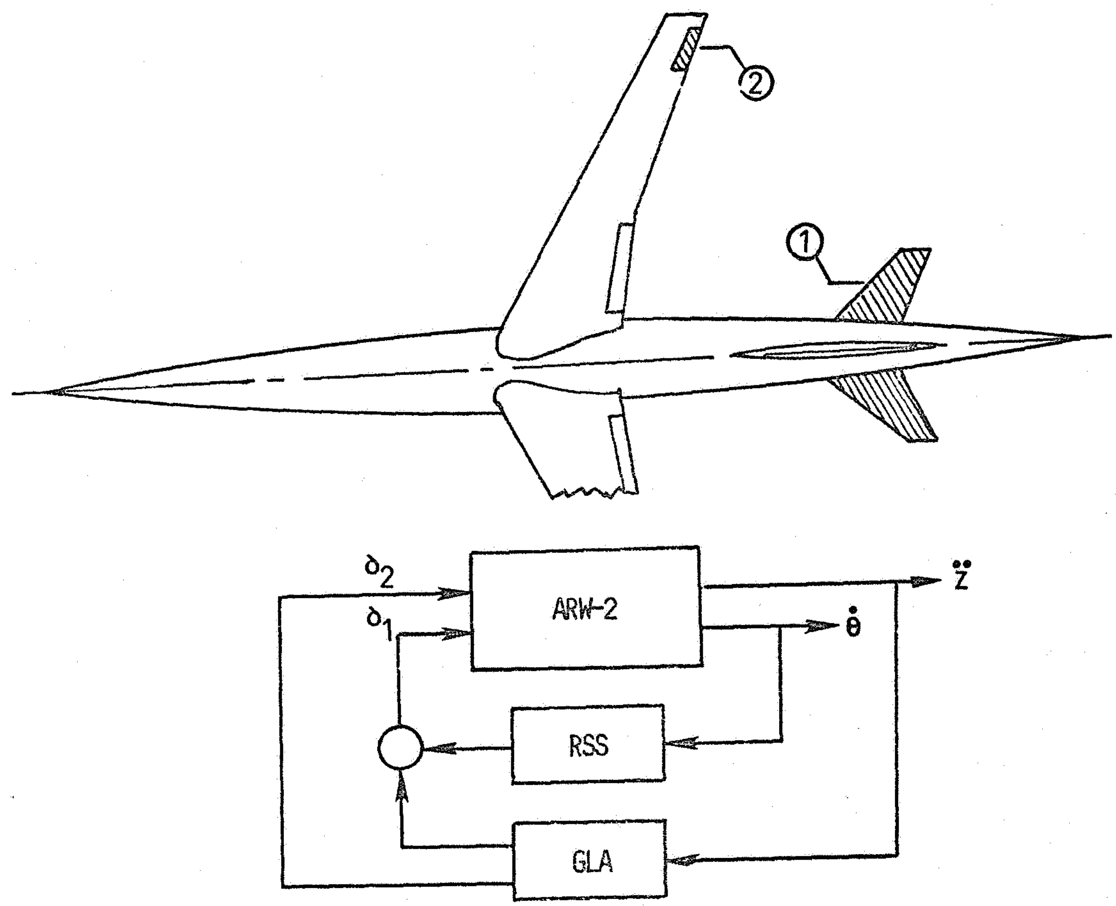

Figure 59(b).

ANALYTICAL TECHNIQUE TO CONTROL THERMAL DISTORTION OF SPACE STRUCTURES BY APPLIED TEMPERATURES

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Extension 3451

RTOP 506-53-53

Research Objective

The objective of the research is to develop analytical procedures to demonstrate the feasibility of using applied temperatures to control thermal distortions in orbiting spacecraft.

Approach

Develop the appropriate equations and solutions thereto to determine the corrective temperatures at specified control points which offset distortions caused by orbital heating. Perform the calculations using closed-form solutions for free-free beams. Extend the equations and solutions to the general case of a finite-element-modeled structure and implement in the EAL finite-element structural analysis program. Perform analyses for a space antenna in low earth orbit.

Status/Plans

Early results obtained for a free-free beam (not shown) and for the radiometer antenna shown in the figure are sufficiently encouraging to warrant additional studies to verify the concept. For example, a reduction in the maximum deformation by a factor of seven was achieved for the antenna. Of particular interest for follow-on studies is the influence of control point location on the effectiveness of the procedure. These theoretical studies have provided and will continue to provide useful information on the performance and usefulness of this concept of thermal distortion control. Additionally, a companion test program will be needed to verify the viability of the technique and to determine its practicality in a variety of simulated orbital heating conditions.

Figure 60(a).

CONTROL OF ANTENNA THERMAL DISTORTION BY CORRECTIVE HEATING

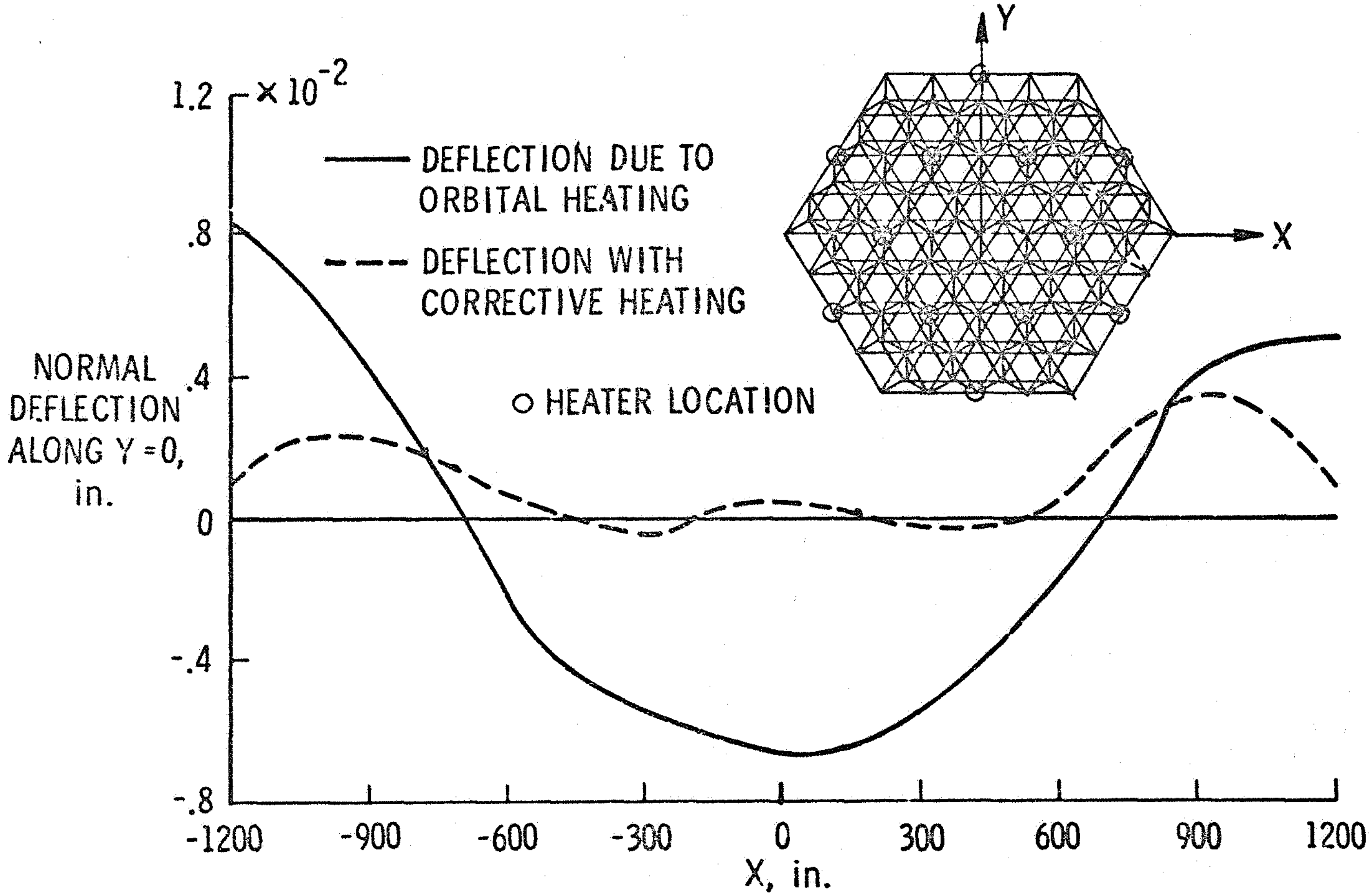

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Figure 60(b).

ARW-1R SCHEDULE

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Multidisciplinary Analysis and Optimization Branch
Extension 3527

RTOP 505-33-43

At least six flights are planned for the ARW-1R. The schedule of performing each succeeding flight test depends on results of the preceding test. At present, it is expected that the B-52 airplane (which is required for launch of the DAST aircraft) will enter a 3 month major inspection in July 1983. A concerted effort will be made to conduct six flights by that time. The accompanying photograph shows the DAST vehicle mounted to a pylon on the B-52 during a recent captive flight test.

Figure 61(a).

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DAST ARW-1R

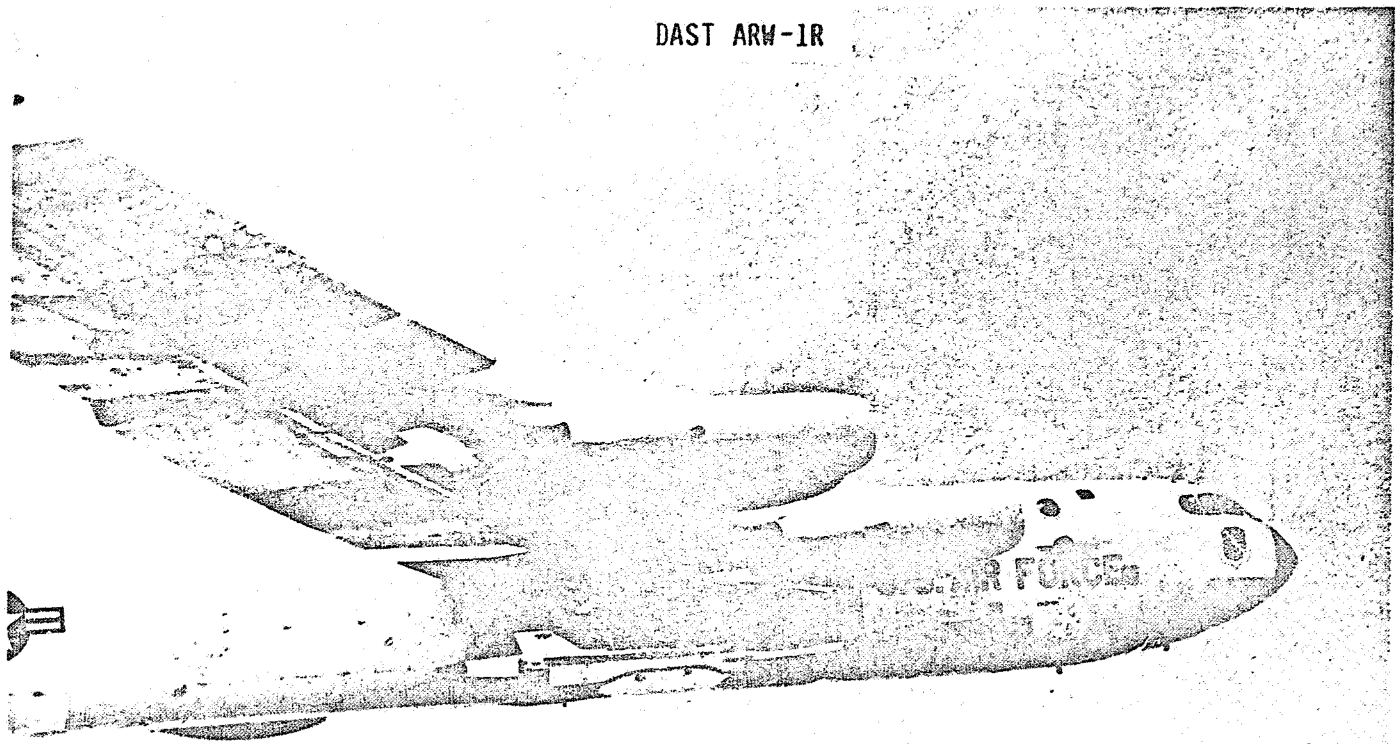

Figure 61(b).

ADVANCED MODULAR OPTIMIZATION PROGRAM

Jaroslaw Sobieski
Multidisciplinary Analysis and Optimization Branch
Extension 3451

RTOP 505-53-53

Research Objective

The objective of this program is to make the best currently available algorithms for finding a constrained minimum in design space available in an efficient and easy to use computer program.

Approach

The state-of-the-art algorithms have been systematically rated for their efficiency and applicability on the basis of direct experience and data reported in the literature. A set of superior algorithms has been selected. A computer program has been designed to contain these algorithms in the form of a library of subroutines callable from a main program prepared by the user. In addition, the common parts of these algorithms have been isolated in the form of subroutines to enable the user to develop new algorithms composed entirely or partly from these existing blocks of code. Development of the program has been carried on to a testing stage, where a number of standard test cases are being used to ascertain its efficiency, accuracy and reliability.

Future Plans

Preliminary series of test runs are scheduled for completion in March 83. The program installation at LaRC is planned for April 83. From that time on, the testing will continue by the developer and by the LaRC users who will supply the developer with their observations as to the program performance. Improvements and corrections will then be implemented as needed through the end of CY 83.

Figure 62.

UNSTEADY AERODYNAMICS
FY-83 MILESTONES/PLANS

RTOP	MILESTONE	SIGNIFICANCE	STATUS
505-33-43	A. STATIC AEROELASTIC TRANSONIC CODE TO COSMIC, OCT. 1982	PREDICT STATIC TRANSONIC AEROELASTIC EFFECTS USING FULL POTENTIAL EQUATION CODE	DELAYED TO MID FY83.
	B. XTRAN3S UNSTEADY PRESSURE CALCULATIONS ON LANN WING, OCT. 1982	COMPARE EXPERIMENTAL UNSTEADY PRESSURES WITH SMALL PERTURBATION CODE RESULTS	CALCULATIONS UNDERWAY
	C. INITIAL ASSESSMENT OF SUSAN TRANSONIC CODE, DEC. 1982	TRANSONIC UNSTEADY AERO CALCULATIONS USING INTEGRAL EQUATION TECHNIQUE	DELAYED TO MID FY83
	D. TRANSONIC FLUTTER ANALYSIS USING XTRAN3S CODE, JAN. 1983	FLUTTER ANALYSIS OF DAST ARW-2 WING USING IMPROVED COMPUTATIONAL GRID	ON SCHEDULE, CALCULATIONS BEGUN SEPT. 1982
	E. INITIAL TESTS OF LASER VAPOR SCREEN FLOW VIZ. APPARATUS, JAN. 1983	VISUAL DISPLAY OF TRANSONIC FLOW PHENOMENA	DELAYED - WILL BE DONE ON "TIME AVAILABLE" BASIS.
	F. SUMMARY REPORT OF ACEE WING UNSTEADY PRESSURE TESTS, FEB. 1983	UNSTEADY PRESSURES DUE TO CONTROL SURFACE OSCILLATIONS ANALYZED AND COMPARED TO TRANSONIC CODE RESULTS	DATA ANALYSIS UNDERWAY

Figure 63(a).

UNSTEADY AERODYNAMICS
FY-83 MILESTONES/PLANS (CONTINUED)

RTOP	MILESTONE	SIGNIFICANCE	STATUS
505-33-43	G. REPORT ON SOUSSA P1.1 APPLICATIONS STUDY, FEB. 1983	APPLICATION OF SOUSSA CODE TO AEROELASTIC CALCULATIONS AND COMPARISON WITH EXPERIMENT	ON SCHEDULE
	H. ASSESSMENT OF 2-D AIRFOIL TRANSONIC FLUTTER CHARACTERISTICS, ON FLUTTER	ESTABLISH EFFECT OF AIRFOIL SHAPE AND STRUCTURAL PROPERTIES	CALCULATIONS UNDERWAY MAY 1983
	I. UNSTEADY PRESSURE TESTS OF ARW-2 WING PANEL, JUNE 1983	OBTAIN TRANSONIC UNSTEADY PRESSURES ON AN AEROELASTIC WING	JUNE 83 TDT TEST ON SCHEDULE
	J. PRELIMINARY UNSTEADY 2-D FULL POTENTIAL CODE RESULTS, JUNE 1983	ASSESSMENT OF IMPROVEMENT PROVIDED BY FULL POTENTIAL CODE	CODE UNDER DEVELOPMENT
	K. SUMMARY REPORT OF CLIPPED DELTA WING UNSTEADY PRESSURE TESTS, JUNE 1983	UNSTEADY PRESSURES DUE TO WING PITCHING AND CONTROL SURFACE MOTION ANALYZED	DATA ANALYSIS UNDERWAY

Figure 63(b).

UNSTEADY FULL POTENTIAL CODE FOR LOADS PREDICTION AND AEROELASTIC ANALYSIS

Woodrow Whitlow, Jr.
Unsteady Aerodynamics Branch
Extension 2661

RTOP 505-33-43

Research Objective:

Currently, unsteady aerodynamic loads for transonic aeroelastic analysis are obtained primarily by solving the transonic small disturbance (TSD) equation. Such analysis is limited because TSD theory fails in the region of blunt leading edges and is applicable only to thin bodies at small angles-of-attack, undergoing small amplitude unsteady motions. Thus, the objective of this research is to enhance our ability to perform aeroelastic analysis by developing a more accurate method for predicting unsteady aerodynamic loads.

Approach:

The objective will be accomplished by using finite difference methods to solve the unsteady full potential equation in conservation form. Since it is not limited to thin airfoils undergoing small unsteady motions and does not fail at blunt leading edges, the full potential approach should be a significant improvement upon TSD methods. The flow equations will be solved in a body-fitted coordinate system to allow the airfoil boundary conditions to be implemented on the airfoil boundary.

Future Plans:

The difference representation of the spatial terms will be constructed such that solutions with entropy-violating expansion shock waves are not admitted. Radiating boundary conditions will be implemented on the computational boundaries to reduce reflected disturbances and to allow the use of a relatively small computational region. Current efforts are aimed at developing a code for two-dimensional analysis.

Figure 64(a).

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FULL POTENTIAL CODE DEVELOPMENT

$$\rho_t + (\rho\phi_x)_x + (\rho\phi_y)_y = 0$$

$$\rho = \left[1 + \frac{1}{2}(\gamma-1)(M^2 - 2\phi_t - Q^2)\right]^{1/(\gamma-1)}$$

- FLUX BIASED DIFFERENCING METHOD
  - CAPTURE SHOCKS IN 2 MESH POINTS
  - ENTROPY CONSERVING
- RADIATION BOUNDARY CONDITIONS
- BODY CONFORMING GRID DESIGNED FOR UNSTEADY APPLICATIONS
- QUASI-STEADY BOUNDARY LAYER CORRECTIONS

Figure 64(b).

ASSESSMENT OF 2-D AIRFOIL TRANSONIC FLUTTER CHARACTERISTICS

Samuel R. Bland and John W. Edwards
Unsteady Aerodynamics Branch
Extension 2661

RTOP 505-33-43

Research Objective:

The objective of this study is to investigate the differences in the transonic flutter behavior of conventional and supercritical airfoils as calculated by finite-difference computational algorithms.

Approach:

The two-dimensional, finite-difference code XTRAN2L is used to determine the aerodynamic forces. This code provides a time-marching solution to the nonlinear, small-disturbance potential equation for transonic flow. The forces resulting from transient disturbances are Fourier transformed to obtain the forces for harmonic motion at all frequencies of interest. A Pade curve-fit is made to these forces to express them in the s-plane for use in a root locus aeroelastic calculation. This technique provides the forces (expensive part of calculation) for any structural parameter variations (inexpensive part of calculation) desired. This pulse technique will be used to examine the airfoil pressure distributions, shock locations, and shock motion detail in order to expose the reasons for the different flutter behavior of conventional and supercritical airfoils.

Future Plans:

The unsteady airloads and pressure distributions of the NACA 64A010 and MBB A-3 airfoils will be examined in detail to understand the differences in their transonic flutter characteristics. Also, the implementation and validity of locally linear, superposition techniques to transonic flutter will be examined.

Figure 65.

DAST ARW-2 TDT TEST

Maynard C. Sandford
Unsteady Aerodynamics Branch
Extension 2661

RTOP 505-33-43

Research Objectives:

The development of active control systems for aircraft demands a thorough understanding of both unsteady aerodynamic and structural dynamics. In the past, efforts have been directed at obtaining transonic unsteady pressure measurements from rigid oscillating wings and control surfaces. Such data is useful for calibrating transonic computer codes but does not address their use in aeroelastic analyses since transonic flows are nonlinear. To assess the ability of transonic computer codes to predict transonic aeroelastic effects unsteady pressure measurements on an aeroelastic wing are needed. NASA's Drones for Aerodynamic and Structural Testing (DAST) program involves flight testing of several Aeroelastic Research Wings (ARW) on a drone aircraft. The ARW-2 wing is instrumented for unsteady pressure measurements and is flexible enough to require a flutter suppression system.

Approach:

Prior to being tested in flight the ARW-2 wing will be tested in the Transonic Dynamics Tunnel. The wind tunnel test of the ARW-2 wing will complement the research objectives of the flight program and expedite obtaining measured transonic unsteady pressure data on an aeroelastic wing for use in validation of analytical prediction methods. Also, flutter analysis of supercritical wings indicates a sensitivity to angle-of-attack changes and the potential exists for obtaining experimental data to verify this predicted flutter phenomena in the wind tunnel test. Finally, the DAST ARW-2 flight operation safety will be enhanced by the wind tunnel test.

Future Plans:

Wind tunnel tests will be conducted in the Langley Transonic Dynamics Tunnel during the summer of 1983 on the ARW-2 right wing panel cantilevered to the tunnel sidewall. A half-body fuselage will be constructed to simulate the correct flow around the wing root section The semispan wing will be properly instrumented with 170 pressure orifices and 2 in situ pressure transducers for calibration purposes.

Figure 66(a).

DAST ARW-2 WING TEST IN TDT

- UNIQUE UNSTEADY PRESSURE DATA ON AEROELASTIC MODEL
- POTENTIAL OF OBTAINING DATA ON ANGLE-OF-ATTACK SENSITIVE FLUTTER
- ENHANCED SAFETY OF FLIGHT OPERATIONS
- TEST IN 1983

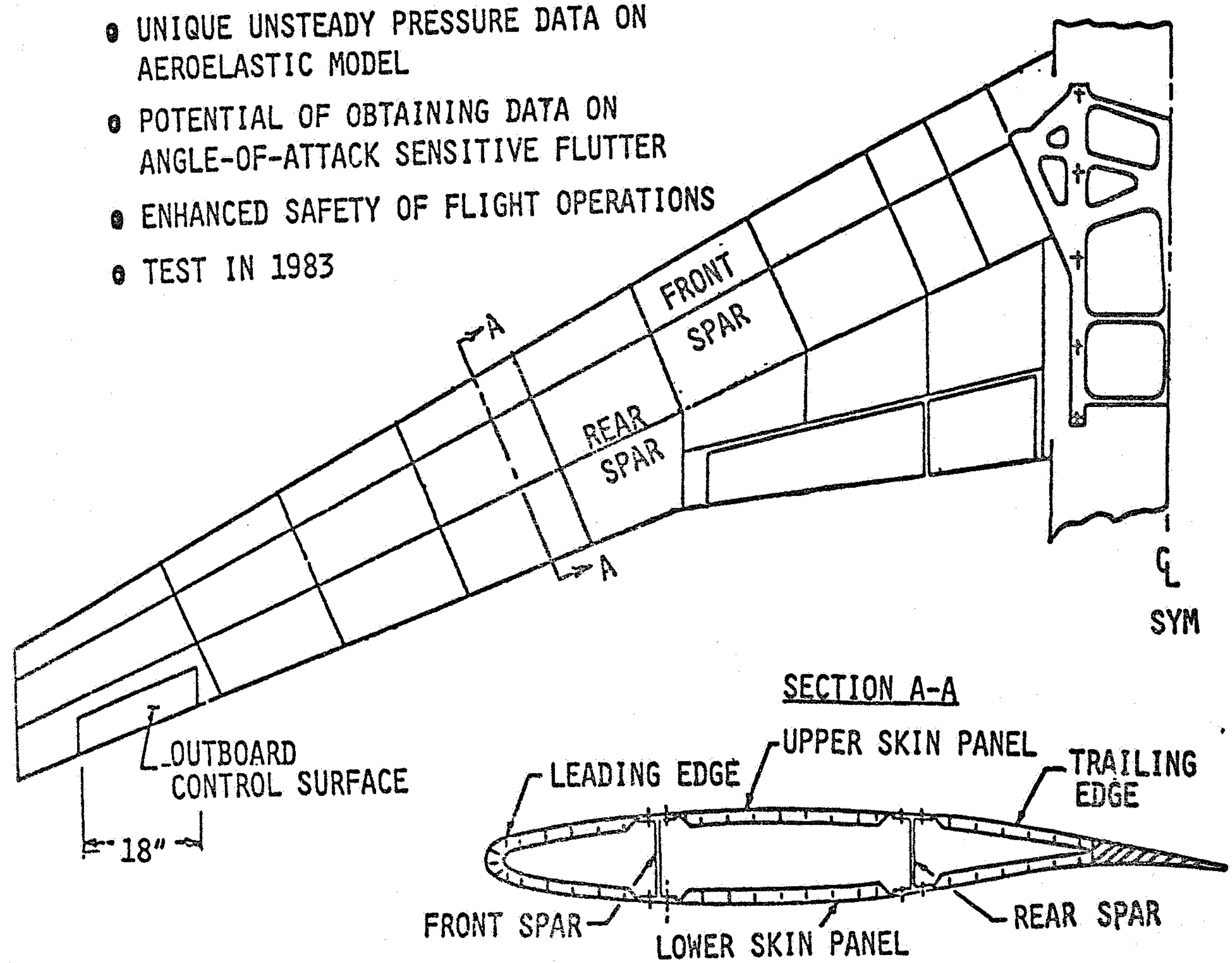

Figure 66(b).

OSCILLATING PRESSURE MEASUREMENTS ON A 2-D SUPERCRITICAL WING IN THE 1/3 METER CRYOGENIC TUNNEL

Robert W. Hess
Unsteady Aerodynamics Branch
Extension 2661

William B. Igoe
NTF Aerodynamics Branch
Extension 2601

RTOP 505-33-43

Research Objective:

High quality unsteady pressure measurements obtained from oscillating airfoils and wings are needed to calibrate transonic computational predictions. The influence of viscosity upon these unsteady airloads needs to be determined since flight Reynolds numbers range up to 100 million whereas past wind tunnel experiments have only reached Reynolds numbers of 10 million. The National Transonic Facility, operating at cryogenic temperatures, will allow testing at flight Reynolds numbers and the LANN wing model will be the first unsteady pressure test in this facility. Prior to testing the LANN wing, valuable two-dimensional unsteady pressure data at Reynolds numbers up to 40 million and operational experience at cryogenic temperatures will be obtained in a test in the 1/3 meter pilot cryogenic wind tunnel.

Approach:

There are four objectives to this research task. They are to (1) measure oscillating pressures at high Reynolds numbers for comparison with developing 2-D unsteady computer codes, (2) measure the extent of change in oscillating pressures on a supercritical airfoil due to change in Reynolds number, (3) compare developed oscillating pressures at low Reynolds number using a suitable boundary layer transition step with oscillating pressures on a base airfoil at high Reynolds numbers and (4) to assess the instrumentation installation and data reduction techniques to be used in the LANN wing test at the NTF.

Future Plans:

A fourteen percent supercritical airfoil (NASA TM 81912) model designed to measure static pressures in the 1/3 m Cryo tunnel will be modified to measure unsteady pressures. The model (6 in chord, 8 in span) is made of 15-5 steel. A complete hydraulic pump unit capable of oscillating the model at frequencies from 4 to 40 hertz is available. The wind tunnel test section will be modified to accomodate the oscillating airfoil unit and the test is planned for the fall of 1983.

Figure 67(a).

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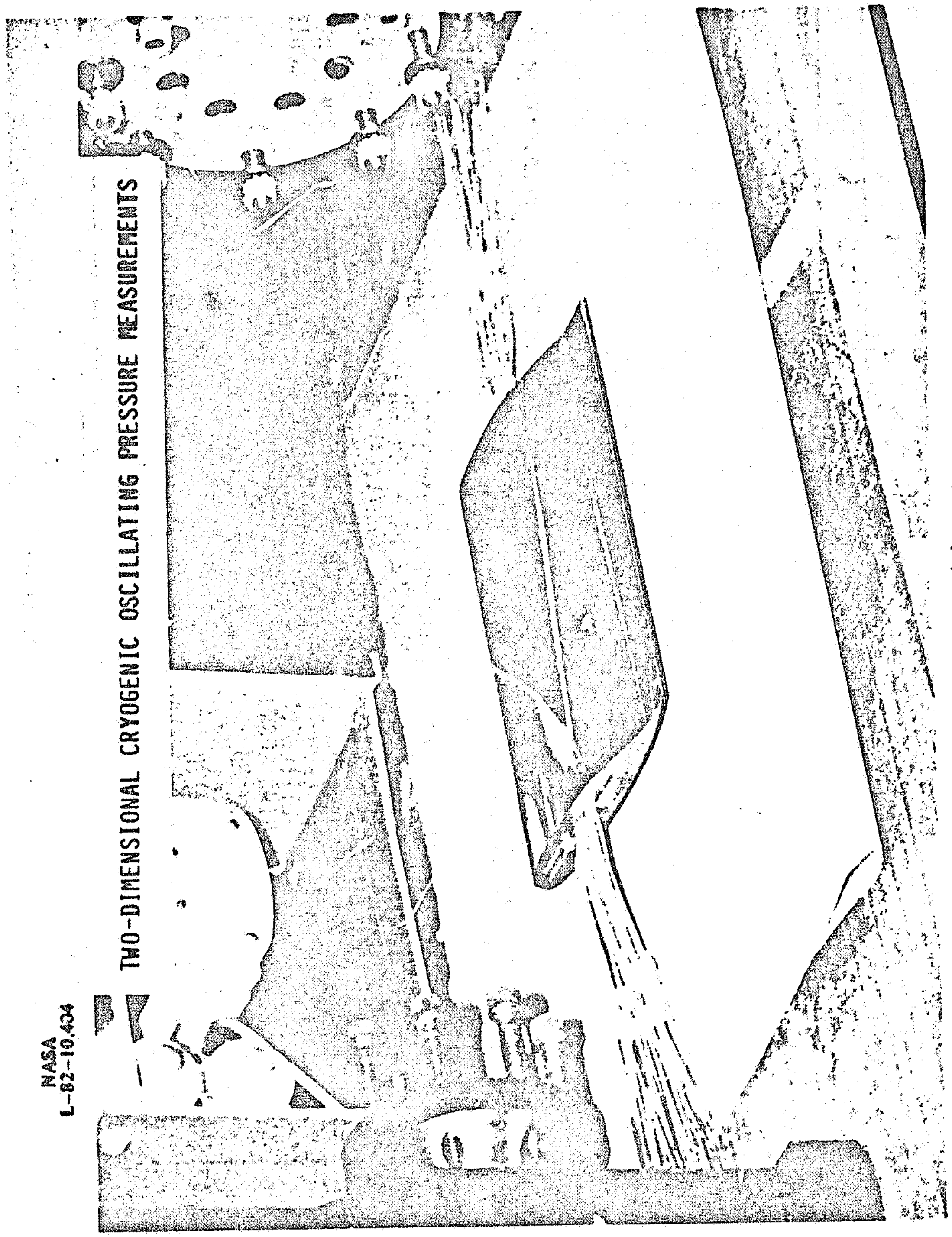

Figure 67(b).

CONFIGURATION AEROELASTICITY
FY-83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
A	533-02-73 505-33-53	COMPLETE DECOUPLER PYLON GROUND TESTS, 2/'83	DETERMINES FUNCTIONAL CHARACTERISTICS OF DECOUPLER PYLON	DECOUPLER PYLON DESIGN IN PROGRESS.
B	533-02-73 503-33-53	DELIVERY OF DECOUPLER PYLON HARDWARE, 5/'83	DECOUPLER PYLON READY FOR INSTALLATION ON F-16 TEST AIRCRAFT	DECOUPLER PYLON DESIGN IN PROGRESS.
C	505-33-53	COMPLETE EXPERIMENTAL STUDIES OF EFFECTS OF WINGLETS ON FLUTTER, 1/'83	PROVIDES PARAMETRIC DATA FOR VALIDATING ANALYTICAL METHODS	ON SCHEDULE.
D	505-33-53	COMPLETE STUDIES OF AERO-DYNAMIC CHARACTERISTICS OF ELASTIC FORWARD-SWEPT WING (FSW), 1/'83	PROVIDES BASIC AERODYNAMIC DATA FOR USE IN FOLLOW-ON AERO-SERVO-ELASTIC STUDIES	MODEL FABRICATION IN PROGRESS.
E	505-33-53	COMPLETE FLUTTER TESTS OF GENERIC ARROW-WING CONFI-GURATIONS, 8/'83	PROVIDES PARAMETRIC FLUTTER DATA FOR VALI-DATING ANALYTICAL METHODS	MODEL DESIGN IN PROGRESS BUT BEHIND SCHEDULE. TESTS WILL BE DELAYED.
F	505-33-53	COMPLETE EXPERIMENTAL STUDIES OF AERO-SERVO-ELASTIC INSTABILITIES OF FORWARD-SWEPT WING (FSW) CONFIGURATION, 9/'83	PROVIDES EXPERIMENTAL DATA FOR CALIBRATING ANALYSES USED TO DEVELOP FSW FLIGHT DEMONSTRATOR	CONTRACT AWARDED FOR MODEL FABRICATION AND CONTROL LAW DESIGN.
G	505-43-33	COMPLETE F-16E (WITH STORES) FLUTTER CLEARANCE TESTS IN TDT, 3/'83	DEMONSTRATES THAT NEW ARROW-WING F-16E AIRPLANE IS FLUTTER FREE AT TRANSONIC SPEEDS	ON SCHEDULE.

Figure 68(a).

CONFIGURATION AEROELASTICITY
FY-83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
H	505-42-23	COMPLETE FLIGHT DEMONSTRATION OF HIGHER HARMONIC CONTROL (HHC) (FIRST PHASE), 10/'82	PROVIDES FULL SCALE CONFIRMATION OF HHC CONCEPT FOR REDUCING HELICOPTER VIBRATIONS	OPEN LOOP FLIGHT TESTS COMPLETE. CLOSE LOOP TESTS BEING DELAYED BY COMPUTER PROBLEMS.
I	505-42-23	DEFINE ROTOR BLADE STRUCTURAL RESTRAINTS FOR USE IN AEROELASTIC OPTIMIZATION OF ROTOR BLADES, 8/'83	DEFINES ALLOWABLE RANGES OF GROSS BLADE PROPERTIES FOR USE IN OPTIMIZATION ANALYSES	WORK PROCEEDING ON SCHEDULE.
J	505-42-23	INITIATE DEVELOPMENT OF HINGELESS ROTOR GUST RESPONSE ANALYSIS METHOD, 5/'83	PROVIDES MEANS FOR DETERMINING SEVERITY OF GUST RESPONSE OF ADVANCED ROTOR SYSTEMS	EARLY PLANNING STAGE
K	505-42-23	COMPLETE HINGELESS ROTOR STABILITY TESTS USING ARES IN TDT, 12/'82	PROVIDES BASELINE STABILITY DATA FOR HINGELESS ROTOR CONFIGURATIONS	ON SCHEDULE. MODEL BEING PREPARED FOR TESTING.
L	532-06-13	COMPLETE CORRELATION OF CH-47D GROUND VIBRATION TEST RESULTS WITH NASTRAN FINITE-ELEMENT MODEL RESULTS, 3/'83	PROVIDES CONFIDENCE IN FINITE-ELEMENT MODELING PROCEDURES	GROUND VIBRATION TESTS COMPLETE. CORRELATION IN PROGRESS.
M	532-06-13	INITIATE CORRELATION OF CH-47D FLIGHT VIBRATION TEST RESULTS WITH NASTRAN FINITE ELEMENT MODEL RESULTS, 1/'83	PROVIDES CONFIDENCE IN FINITE-ELEMENT MODEL PROCEDURES	PROGRAM PLAN ALMOST COMPLETE.

Figure 68(b).

CONFIGURATION AEROELASTICITY
FY-83 MILESTONES/PLANS

NO.	RTOP	MILESTONE	SIGNIFICANCE	STATUS
N	532-06-13	OBTAIN INDUSTRY CONSENSUS FOR NASA/INDUSTRY EXERCISES IN DEVELOPING NASTRAN FINITE-ELEMENT MODELS FOR A VARIETY OF AIRFRAMES, 1/'83	STRENGTHENS U.S. HELICOPTER INDUSTRY CAPABILITY FOR USING FINITE ELEMENT MODELS FOR VIBRATION PREDICTION IN THE DESIGN PROCESS	INITIAL DISCUSSIONS WITH SOME INDUSTRY REPRESENTATIVES CONDUCTED.
O	532-06-13	OBTAIN UNIVERSITY CONSENSUS FOR NASA/UNIVERSITY EXERCISE IN DEVELOPMENT OF CURRICULUM FOR ROTORCRAFT VIBRATION ANALYSIS, 2/'83	DEVELOPS WITHIN U.S. UNIVERSITIES ACADEMIC PROGRAMS FOR TRAINING STUDENTS IN ROTORCRAFT VIBRATION ANALYSIS	EARLY PLANNING STAGE.
P	532-06-13	COMPLETE PRELIMINARY EVALUATION OF ROTOR MATHEMATICAL MODEL ESPECIALLY TAILORED FOR AIRFRAME VIBRATION ANALYSIS, 3/'83	PROVIDES ANALYSIS METHOD SUITABLE FOR INCLUSION IN ROTORCRAFT DESIGN ANALYSIS	BASIC APPROACH BEING DEFINED.
Q	532-06-13	DEVELOP COMPUTATIONAL PROCEDURES FOR TWO-DIMENSIONAL INTEGRATING MATRICES	PROVIDES NEW NUMERICAL PROCEDURES FOR SOLVING VIBRATION PROBLEMS	ON SCHEDULE

DECOUPLER PYLON PROGRAM

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Extension 2661

RTOP's 505-33-43 and 533-02-73

Research Objective

To demonstrate passive suppression of wing/store flutter on a modern lightweight fighter airplane.

Approach

The Decoupler Pylon Program consists of analyses, wind tunnel tests, and flight tests of a NASA patented pylon. The decoupler pylon dynamically isolates the wing from external store pitch inertia effects by means of soft-spring and damper components. An alignment system can be incorporated to minimize static pitch deflections of the store due to maneuvers and aerodynamic loads. Analyses and wind-tunnel tests of YF-17 and F-16 flutter models with stores have shown increases in flutter dynamic pressure in excess of 100-percent over the same stores mounted on standard pylons.

The flight test program will demonstrate flutter suppression on the F-16 with the same store configuration tested in the wind tunnel. The decoupler pylon goal is to demonstrate a 70-percent increase in flutter dynamic pressure over a production pylon. The flight tests will also bring into focus the effects of turbulence, flight maneuvers, store ejection and flight control system interactions.

Status/Plans

Two decoupler pylons are now being fabricated for flight test. Manufacture and instrumentation will be completed in February 1983. Pylon ground tests will be performed to document system stiffness, damping, and alignment system stability characteristics. One pylon will be proof-tested to verify structural adequacy and also will be used for store ejection tests.

The flight test F-16 is to be received at NASA Dryden in October 1983. Aircraft instrumentation and vehicle/pylon ground tests will be performed with flight tests scheduled to begin in the second half of 1984.

Figure 69(a).

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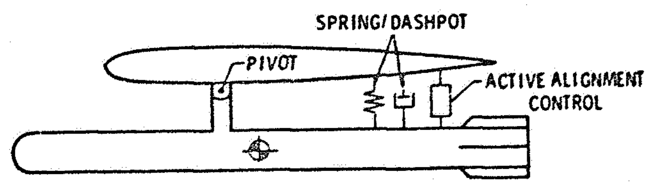
DECOUPLER PYLON — A PASSIVE FLUTTER SUPPRESSOR

JOINT LaRC AND DFRF PROGRAM



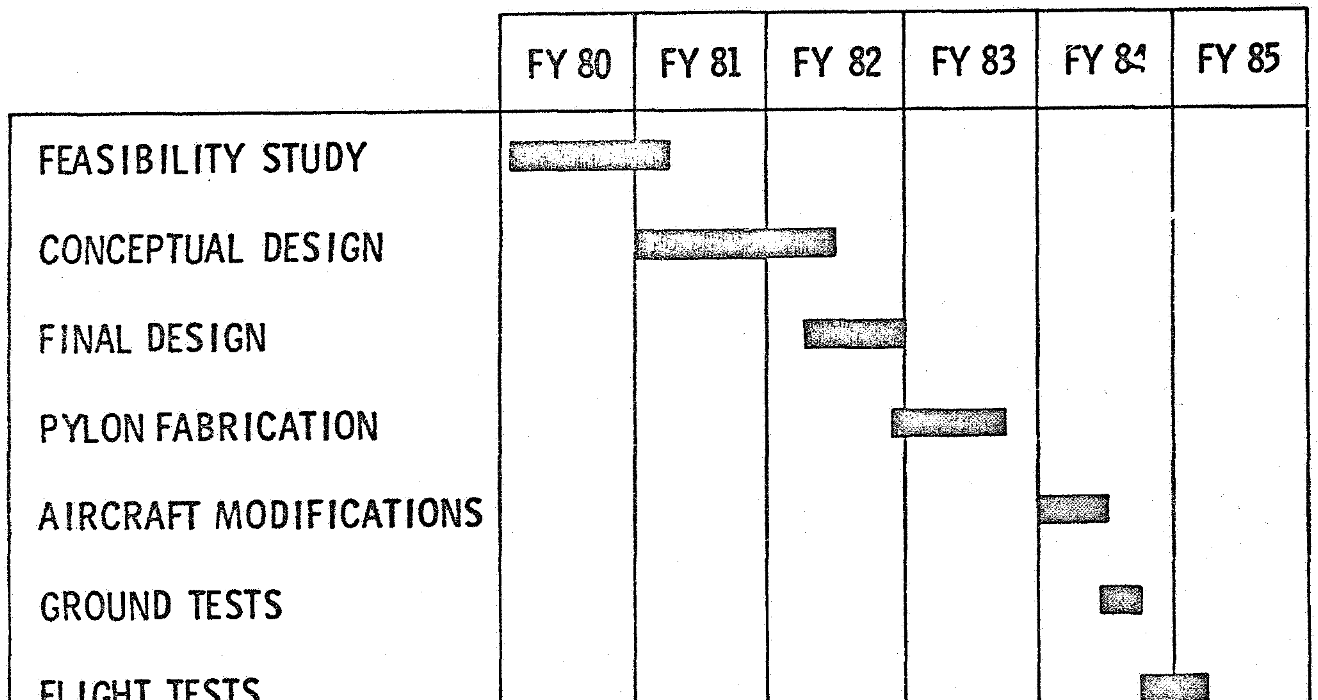


Figure 69(b).

MODIFICATIONS TO UPGRADE THE LANGLEY TRANSONIC DYNAMICS TUNNEL (DENSITY INCREASE)

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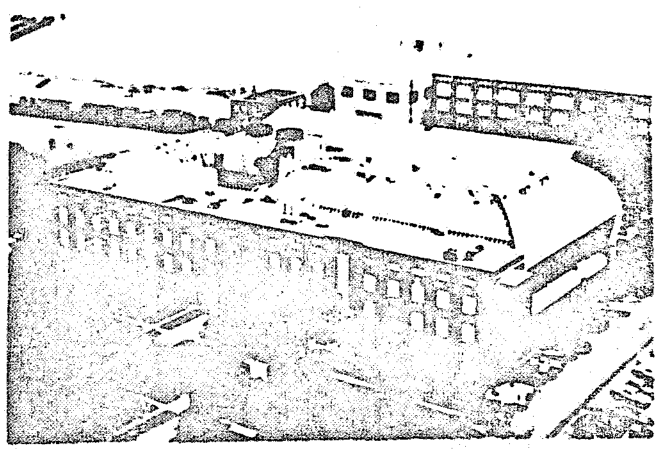
Background: The TDT is designed for and dedicated to studies and tests in the field of aeroelasticity and has special features which make it a national resource for flutter and buffet tests. Some of these features are its large 16 ft. x 16 ft. subsonic-transonic flow slotted test section, the ability to use dense Freon-12 gas or air as a test medium, a computer-controlled data acquisition system specifically designed to handle large quantities of dynamic data in near real time, special model mounting systems, a gust generator, a "flutter-stopper," safety screens upstream of the tunnel fan, and good model visibility while testing. The facility is used to verify the flutter and aeroelastic characteristics of most U.S. high-speed aircraft designs; for rotorcraft and active controls research; for flutter, buffet, and ground-wind loads tests of the Space Shuttle and other launch vehicles; and for confirmation of unsteady transonic flow theory. The increased density capability is needed chiefly for development testing involving the flutter clearance and validation of the flutter characteristics of high-speed aircraft and space vehicles such as the Shuttle. Models of these aircraft must be dynamically and aeroelastically scaled if the tests are to be valid. In addition to simulating the external shape, the stiffness, and stiffness distribution, these models must also simulate the mass density ratio which is the ratio of the distributed mass of the vehicle to the mass of the flight medium surrounding it. As airplanes become lighter (more structurally efficient), as with the use of composite major structures, or as they incorporate the use of active controls (which means the models have to employ relatively heavy active control hydraulic systems internally), it becomes increasingly difficult to fabricate models which are light enough to match full-scale mass-density ratios with current TDT density capability.

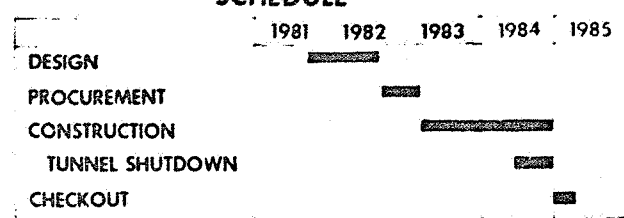
Approach: This FY 83 C of F project will provide for increasing the maximum test density by 50 percent in the Mach number range from 0.6 to 1.2. The increased density capability will be provided by rewinding the existing fan motor to increase the power rating from 20,000 hp to 30,000 hp. Additional tunnel cooling capacity will be provided to accommodate the increased tunnel power limit. Other major modifications include changes to the electrical power distribution system and installation of a new speed control system.

Status/Plans: The design of the required modifications has been completed by DSMA Engineering Corporation. This design provides for dividing the work into a series of independent work packages to be performed by separate contractors. Overall supervision of the work will be provided by a LaRC project manager assisted by a team of engineers expert in the various phases of the work. Preparation of procurement packages for the various work packages is now in progress. Approximately nine separate contracts will be awarded beginning in early CY 83. Procurements will be scheduled so that long lead time items can be purchased/fabricated prior to the tunnel shutdown scheduled to begin in mid 1984. Installation of the modifications are expected to take about six months followed by a three months checkout period. The TDT is expected to be fully operational with the increased density capability in April 1985.

Figure 70(a).

TDT DENSITY INCREASE





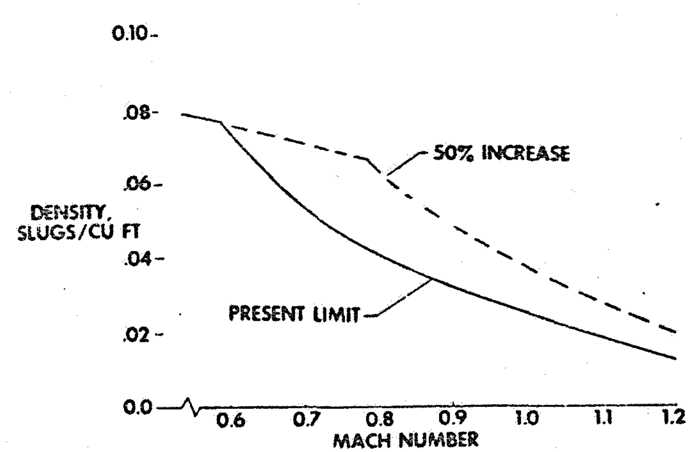


Figure 70(b).

AEROELASTIC STABILITY OF HINGELESS AND BEARINGLESS ROTORS

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RTOP 505-42-23

Research Objective

The immediate objective of this project is the development of a safe and accurate technique for testing hingeless rotors in the TDT and the validation of predictive analytical procedures. This objective will be the basis for the establishment of a stability clearance procedure for hingeless and bearingless rotorcraft that is analogous to the flutter clearance of fixed-wing aircraft. In addition, it will provide a means for conducting research studies aimed at developing rotors with improved aeroelastic characteristics, such as less vibration and lower oscillatory stresses.

Approach

The development of the testing technique requires an improved test capability in the Helicopter Hover Facility (HHF), acquisition of a proven pretest analytical prediction tool, invention of a real-time damping estimation technique, and adaption of an accurate and efficient on-line damping measurement procedure. The HHF capabilities are needed to investigate ground resonance instabilities, to establish structural safety before TDT testing, and to develop instrumentation and data reduction techniques. Major tasks now underway to improve the HHF include the programming of a simple digital data acquisition system, a better hydraulic supply system, and a control system trim resolver that will automatically follow rotor RPM changes. For both hover and forward flight the analysis for hingeless rotors written by Wayne Johnson at Ames is expected to be adequate to direct the attention of the tunnel test engineer to potential instabilities. This program, CAMRAD, will also be correlated to the TDT measurements in order to validate its usefulness as a design tool for new rotors with improved aeroelastic characteristics.

Two damping measurement techniques are required for the best testing efficiency and accuracy. A damping estimate that lags real-time by less than 15 seconds will allow the tunnel speed and rotor trim to be varied with efficiency and safety. An accurate measurement of the damping after each test point has been reached and trim stabilized will be made using the moving block technique. This measurement will be the primary published data as well as the controlling indicator of model safety.

Future Plans

The testing in the TDT and the HHF will be extended to cover higher frequency instabilities such as air resonance. Both the experiments and the analyses will be extended to include bearingless rotors, and the feasibility of new test techniques to simulate the body motions of a helicopter in flight will be explored. The application of tailored structural concepts such as optimized spanwise distribution of stiffness and mass in combination with advanced aerodynamic concepts including new airfoils and optimized twist distributions is expected to produce an optimized aeroelastic rotor.

Figure 71(a).

HINGELESS ROTOR TEST IN HELICOPTER HOVER FACILITY

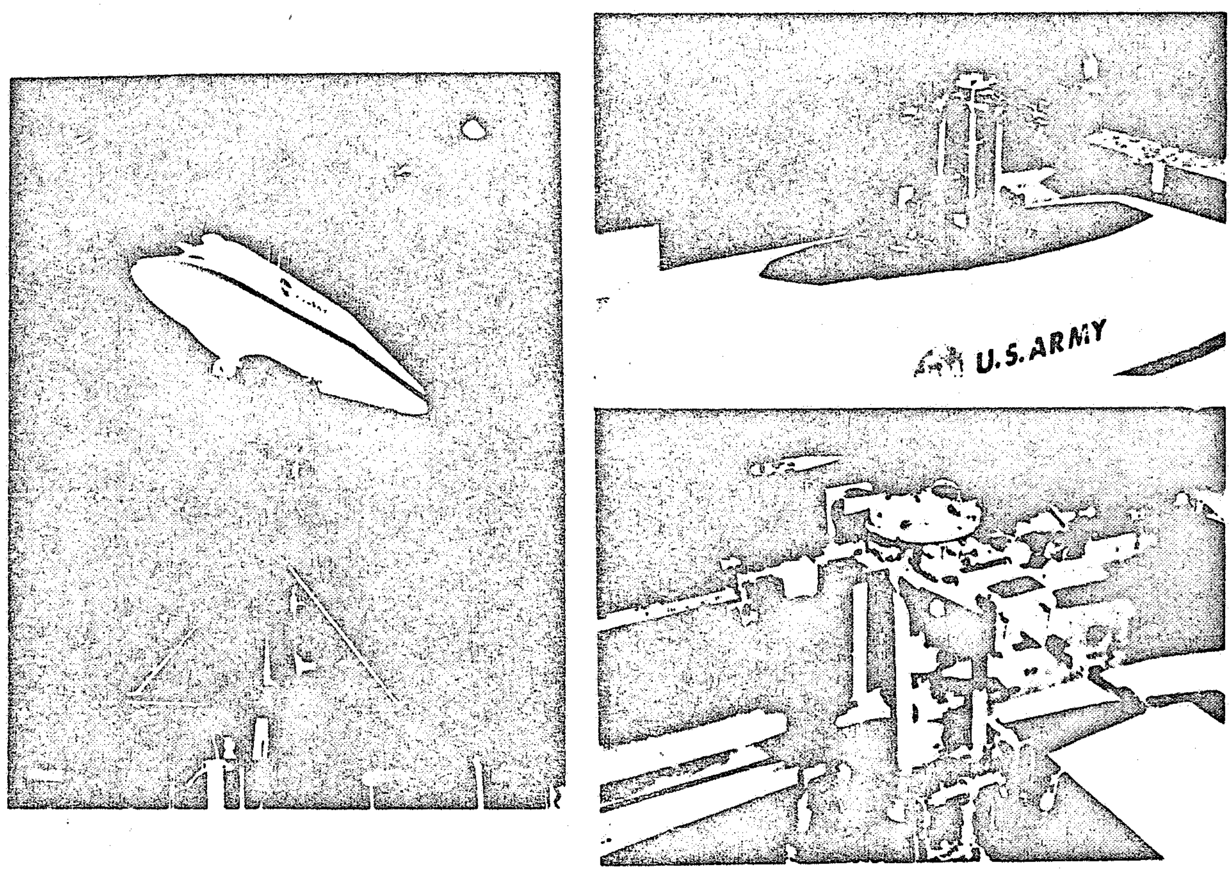

Figure 71(b).

A NATIONAL CAPABILITY TO ANALYZE VIBRATION AS PART OF HELICOPTER STRUCTURAL DESIGN

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Extension 2661

RTOP 532-06-13

Research Objective

Helicopters are prone to vibrations which can seriously degrade both service life and ride quality. With only a few exceptions vibrations problems have not been identified and attacked until the flight test and operational stages. There is now a recognized need to account for vibrations during the analytical phases of design. The advent of modern methods of computer analysis has provided the opportunity to achieve such a capability. The objective is to emplace in the United States a superior capability for design analysis of helicopter vibrations.

Approach

The following nine types of program elements have been identified: (1) Finite element models - sheet metal airframes, (2) Finite element models - difficult components, (3) Finite element models - airframes with composites components, (4) Coupled rotor-airframe vibrations analysis, (5) Procedures to evaluate vibration control devices, (6) Fatigue loads analysis, (7) Airframe damping models, (8) Scientific methods for improving airframe finite element models based on test data, and (9) methods to optimize airframe structures subject to vibrations constraints. Each element culminates in a major application activity where an analysis method is applied in an industrial environment and the results are correlated with appropriate tests. Industry-wide critique of the applications will be maintained. In some cases application studies can be started immediately. Other cases require preceding scientific development and/or implementation of computer codes. The program is proposed to cover the underlying scientific developments. It is also proposed to cover necessary implementations of computer codes but to the breadboard stage only. Some of the underlying development will be, scientifically speaking, fundamental and difficult. It is anticipated that helicopter manufacturers will conduct under appropriate NASA contracts several application activities for different vehicles.

Future Plans

The Langley Research Center Structures Directorate will plan and advocate this program during FY 1983 with the intention of initiating work by the companies at the beginning of CY 1984.

Figure 72(a).

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PROGRAM FOR A SUPERIOR CAPABILITY TO ANALYZE VIBRATIONS AS PART OF HELICOPTER DESIGN

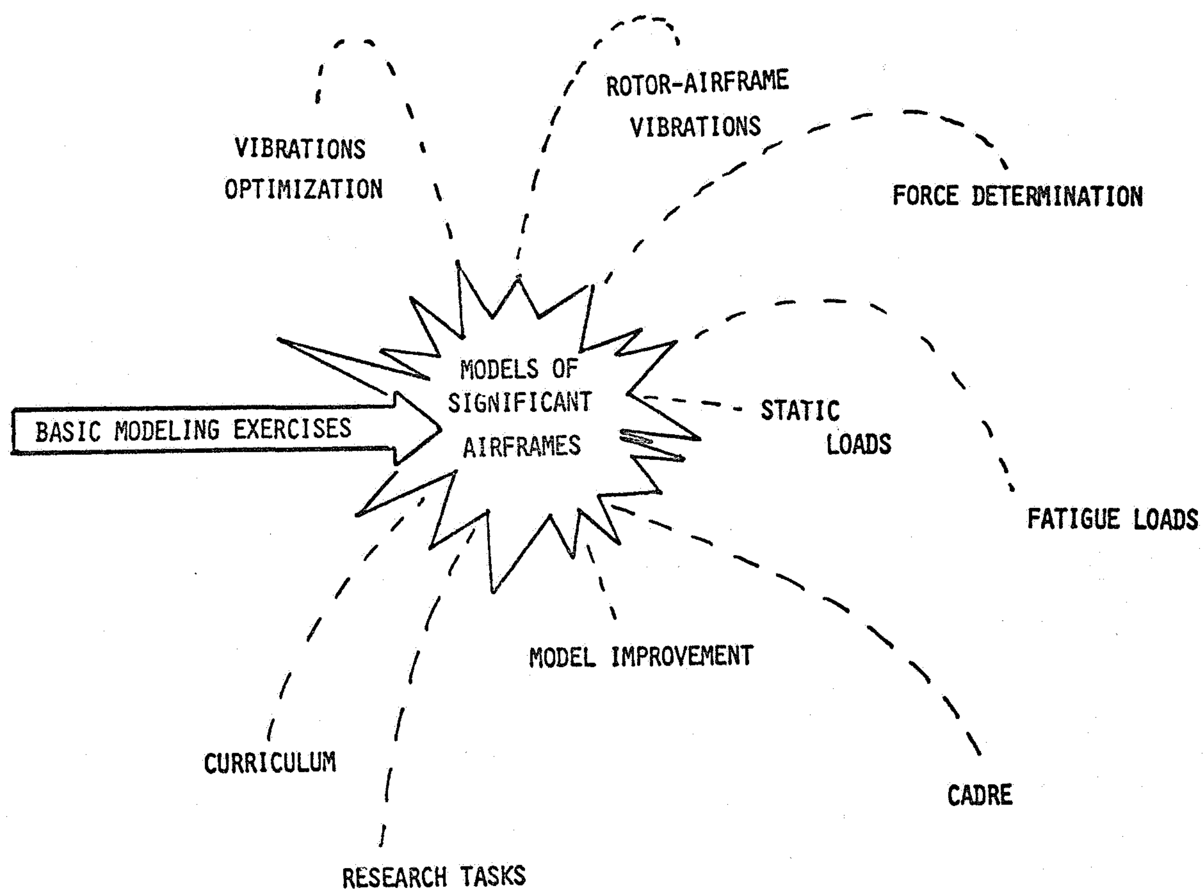

Figure 72(b).